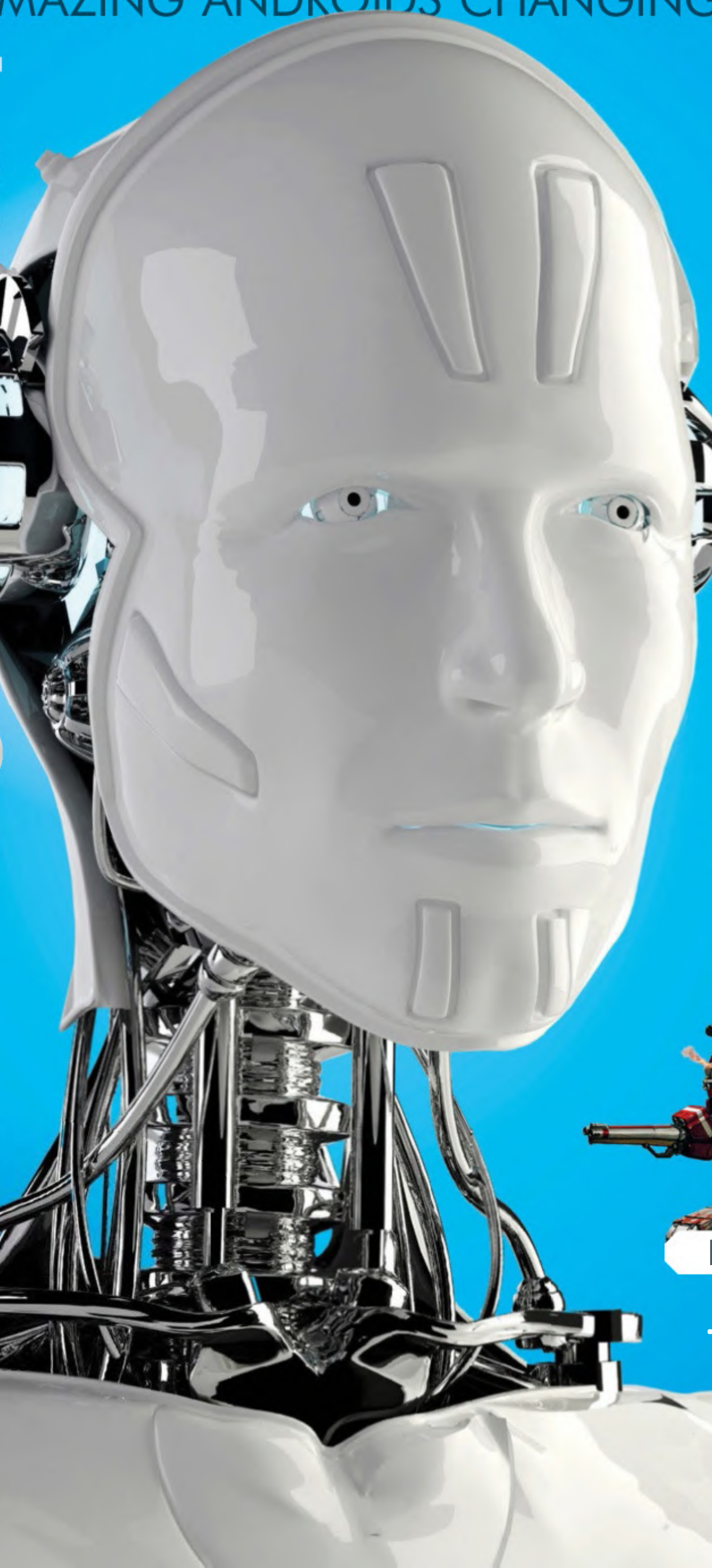
HOW IT WORKS BOOK OF

NEW

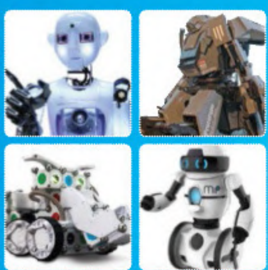
ROBOTS

DISCOVER THE AMAZING ANDROIDS CHANGING THE WORLD



10 BEST BOTS

The greatest robots you can buy right now



AT YOUR SERVICE

The helpful robots that make your life easier

ASTROBOTS

Meet the space robots taking giant leaps

BUILD YOUR FIRST ROBOT

Using basic code and kit

148 PAGES OF ROBOTIC TECH

SEVEN ROBOT FIRSTS

Pioneering machines that led the way

LEARN ABOUT

• ROOMBA • GOPIGO
• PEPPER • MEGABOTS
• HITCHBOT • BB-8
• MILITARY BOTS

WELCOME TO

HOW IT WORKS BOOK OF

ROBOTS

Robots are awesome, in every sense of the word, invoking reactions from excitement to fear to awe. As scientists continue to find new ways to replicate human behaviours, and machines perform functions that we never thought they could, they become ever more present in our lives. In this book, you'll trace back the history of the first robots and discover the best bots that you can own, right now. You'll gaze into the future of robotics and look a little closer to home at those designed to make your house intelligent. You'll discover how robots are making the universe smaller than ever as they help us find new worlds, before meeting the megabots who fight for sport. Finally, you'll learn how to make your very own robot, using a simple Raspberry Pi kit and some code. So, get ready to learn about the machines that are changing the world and discover how you can make your mark.

HOW IT WORKS
BOOK OF

ROBOTS

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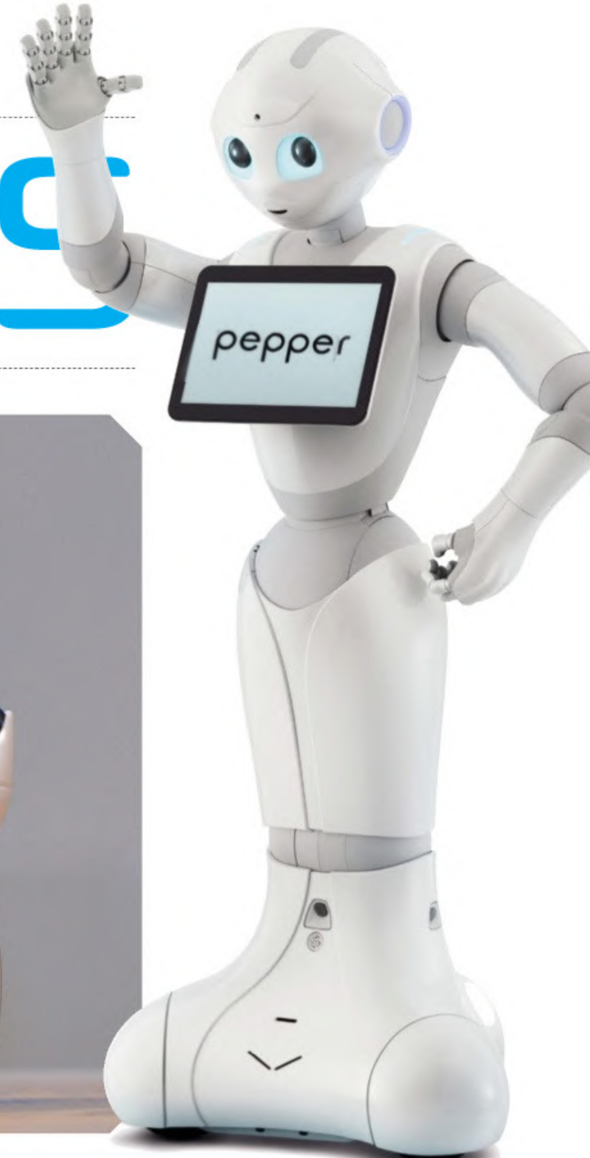

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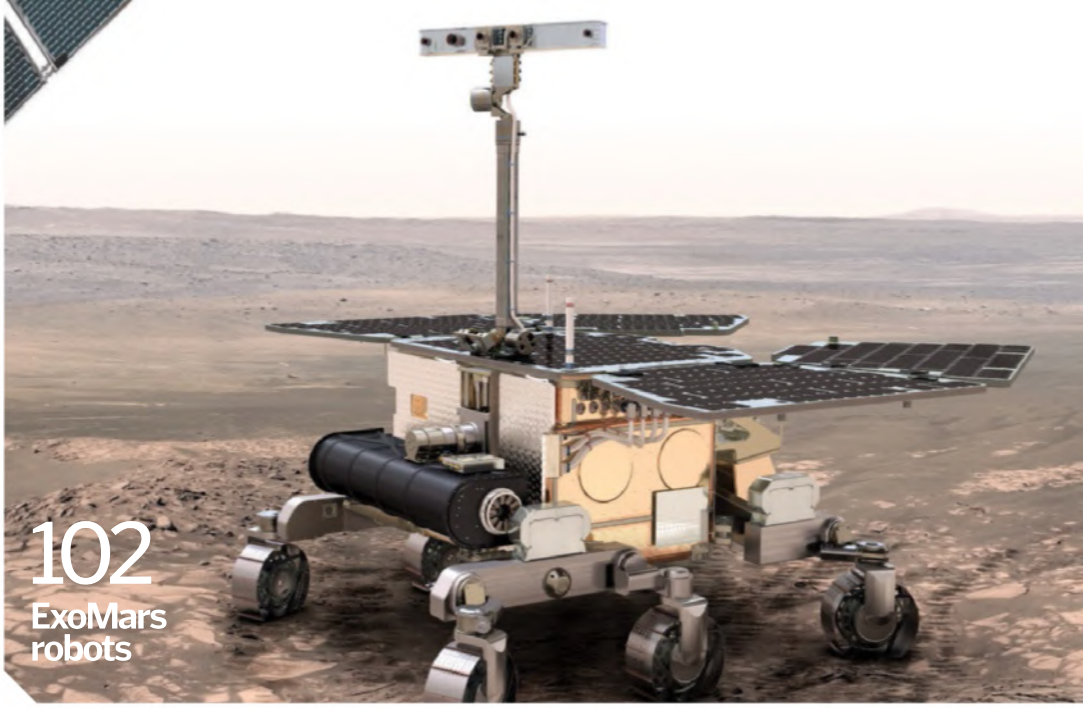

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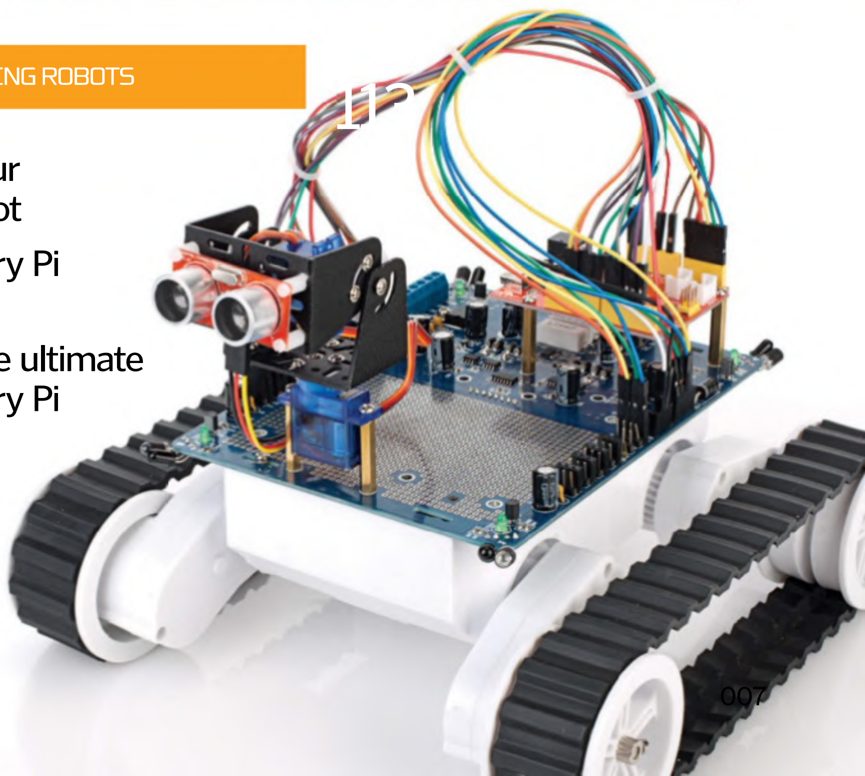

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TOP 10 ROBOTS MONEY CAN BUY

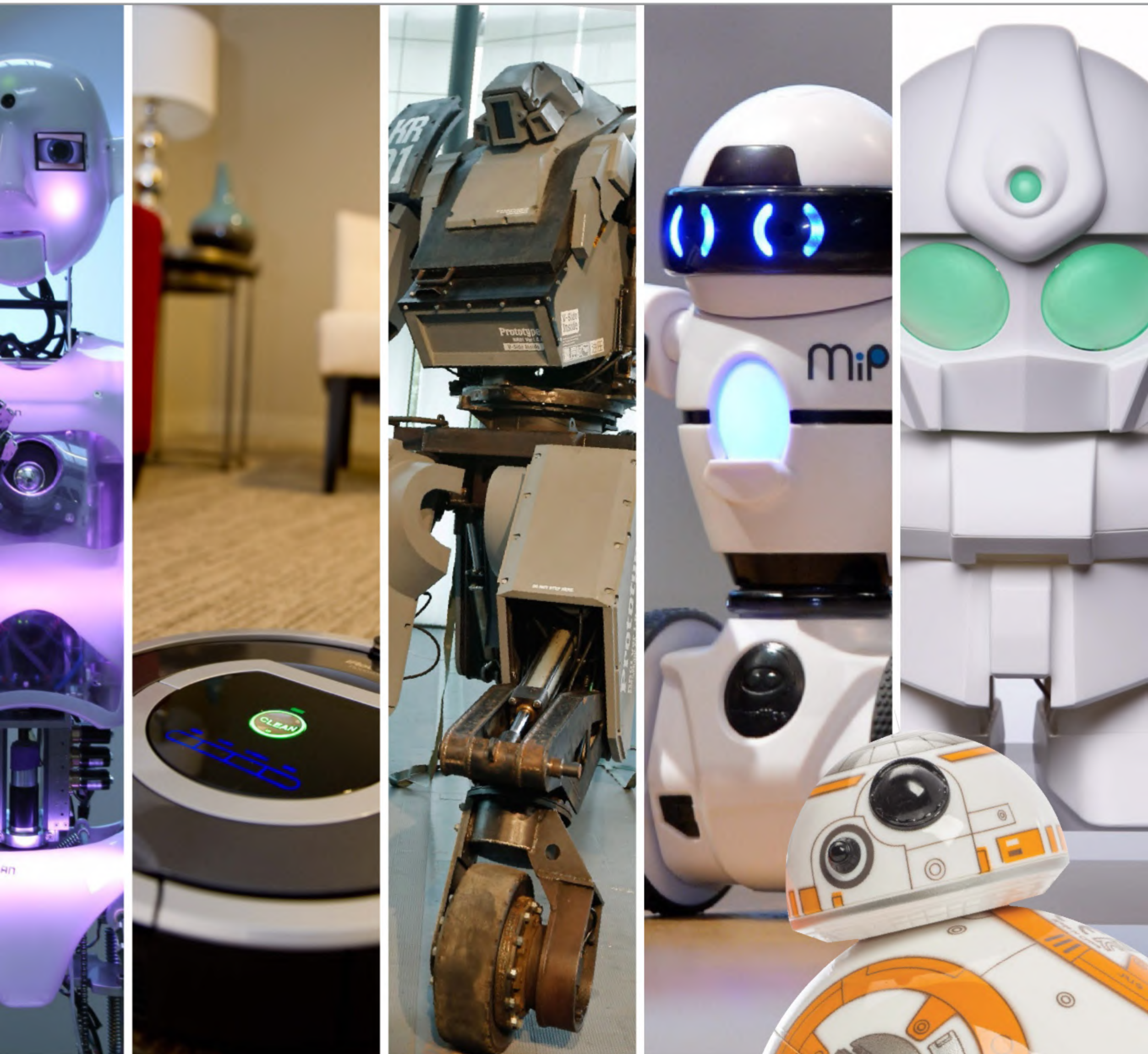
The world of robotics has something for everyone, but which one is perfect for you?

When Czech writer Karel Capek first used the word 'robot' to describe a fictional humanoid in his 1921 science fiction play, *R.U.R.*, he had no idea that one day, almost every person on the planet would be familiar with his then fictional term. Less than 100 years later, robotics is set to become the next trillion-pound industry; it's a matter of when rather than if.

As advancements in robotics made robots smaller and cheaper, they quickly found their way into the shops. Today, a colossal variety of different robots are available to buy, from small programmable toys to monstrous humanoid suits of armour. Entertainment robots are becoming increasingly popular, many of which make use of a piece of technology we all seem to have these days: a smartphone. These toys range from small race cars and helicopters to robotic puppies, and are soon to be the top of every child's Christmas wish list.

If you're looking for something more practical, there are a whole host of home robots that can vacuum your floors or even mow the lawn,

DID YOU KNOW? *Studies suggest that two thirds of Roomba vacuum cleaner owners are emotionally attached to their robots*



without you having to lift a finger. Home security robots are also just starting to come onto the market, such as the Robotex Avatar III, which can patrol your house on its own while it streams HD video directly to your smartphone. Not exactly RoboCop, but this robot will give you valuable peace of mind when you're not at home.

Helping the elderly is another major field of robotics; as our population continues to age, these robots could become a vital part of everyday life for the older generations. Personal robots really come into their own in this regard, particularly telepresence robots that are able to move around the house and interact with people at eye level, reminding them to take their medication or even just providing a friendly face to talk to.

So which of these types of robot is right for you? We've put together a list of our ten favourite robots for you to choose from, ranging from entertainment robots that everyone can afford to the pinnacle of today's robotic engineering, which will require you to re-mortgage your house and possibly your family's homes too!

Affordable robotics

Nowadays anyone can own their own robot, thanks to huge advancements in the field of personal robotics

Ten years ago, personal robots were seen as something only the rich could afford. Times have quickly changed however; today you can pick up a fairly nifty robot for well under £50, including brilliantly educational, build-your-own robot kits that teach children about programming, engineering and computing in a fun and engaging manner. The vast developments that have been made in computing are relevant across most fields of robotics, and have enabled this form of technology to become cheaper as it has become more widely available and increasingly mass produced. Key components of intricate robotics, such as vision sensors and gripping systems, have also advanced to such an extent that robots have become smarter, highly networked, and are able to perform a wider range of applications than ever before.

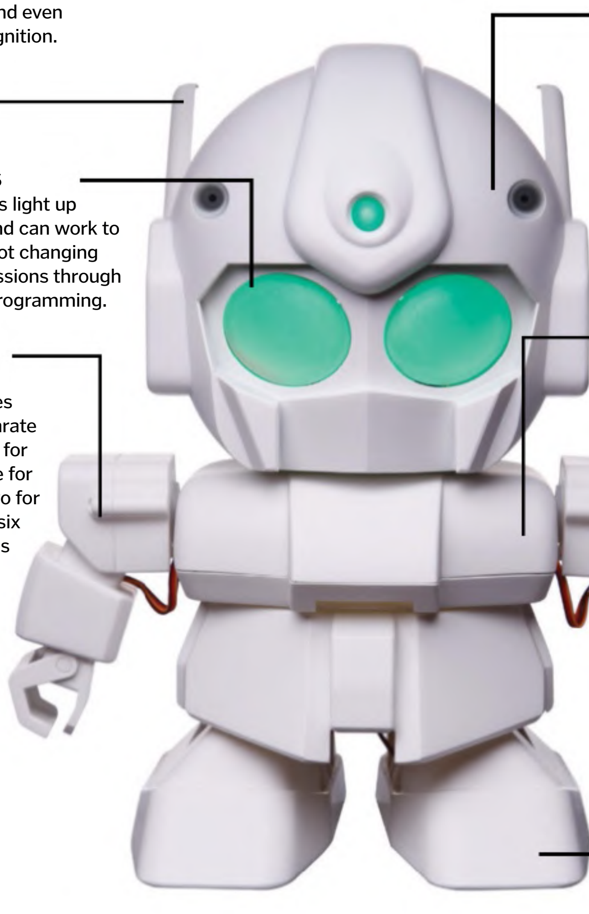
Thanks to these advancements, prices have rapidly fallen while performance has increased exponentially. All in all this is brilliant for the consumer, as robots that were recently considered cutting-edge are now older but not obsolete, making them affordable for the masses.

1: Rapiro

This cute, affordable and easy-to-assemble humanoid has endless customisation options

Price: £330
Country of origin: Japan
Main function: Entertainment

It may be small, but the Rapiro is very much capable of acting big should you programme it to do so. It relies on a Raspberry Pi for its processing power and actually takes its name from 'Raspberry Pi Robot'. Its ability to be continually upgraded and changed is Rapiro's main strength; the more you put into it the more you get out. The possibility to learn about robotics with Rapiro is a huge selling point. You do have to buy the Raspberry Pi separately, but it's relatively inexpensive so don't hold it against this cute little robot. Rapiro is recommended for anyone aged 15 or over, but younger children can have a huge amount of fun with Rapiro under the supervision of an adult.



2: WowWee MiP

This loveable robot buddy will spin-dance to music and express its own emotions with shouts and groans

Price: £89.99
Country of origin: China
Main function: Entertainment

The faintly humanoid MiP sits on Segway-like parallel wheels, which it uses to furiously dart across all flat surfaces. Lots of technology is packed into the relatively small frame, including a head-mounted microphone, LED eyes, infrared transmitters and a speaker. Using hand gestures, it can be directed to move or dance, which it does with impressive balance considering it's resting on two parallel wheels. This provides hours of fun, especially when its immersive personality starts to interact with you as you play with it more.

WowWee strongly recommends you download the accompanying app, which is free and available on iOS and Android. This app will allow you to access MiP's extra features and makes it even easier to control: simply swipe forward with your left thumb to move forwards while using your right thumb to steer. You can also perform a few extra dance moves, but this is a minor feature compared to the ability to control MiP's movements directly.

3: Star Wars BB-8 App-Enabled Droid

The perfect robot for any Star Wars-obsessives, the BB-8 will provide hours of fun for all ages

Price: £129.99
Country of origin: United States
Main function: Entertainment

It may only be 11.4 centimetres (4.5 inches) tall and incredibly cute, but the BB-8 App-Enabled Droid has an abundance of cool features that are incredible considering its size. It can be operated using your smartphone, which it connects to via Bluetooth, and can respond to voice commands by listening and responding to what you say. A battery life of an hour and a 30-metre (100-foot) range means you really can explore the world around you. The more you use the BB-8, the better it will respond to your commands, understanding how you like to use it and tailoring its operation to suit you. Much like its cinematic predecessor R2-D2, the BB-8 can record, send and view holographic videos, albeit in the virtual world only (fans of George Lucas' movies will still be impressed). The BB-8 showcases just how much clever robotics technology has become affordable to the masses, and will no doubt be a hit with children and adults alike now that the Star Wars franchise is back in full swing.

4: Sphero 2.0

The original app-enabled robotic ball, the Sphero is as relevant today as when it first rolled onto the scene in 2013

Price: £79.99
Country of origin: United States
Main function: Entertainment

Programmed to evolve
Sphero's intelligence is impressive to start with, but it can be hacked and programmed by the owner to give it even more tricks than it already possesses.

Ramp up the fun
With additional ramps, you can really start to enjoy the power of the Sphero's electric motor by performing cool stunts.

Glowing LEDs
Sphero's LEDs are ultra-bright, glowing in over a million different colours depending on your personal preference; it's fully customisable.

Strong design
The Sphero has a tough polycarbonate outer shell that protects the advanced technology housed inside from all kinds of potential damage.

Clever charging
You don't need to plug the Sphero in when its battery runs low, simply sit it on its base and let the ingenious inductive charging system do the rest.

Great connectivity
Connect your Sphero with any Bluetooth-enabled device, such as your smartphone, and you are ready to start rolling!

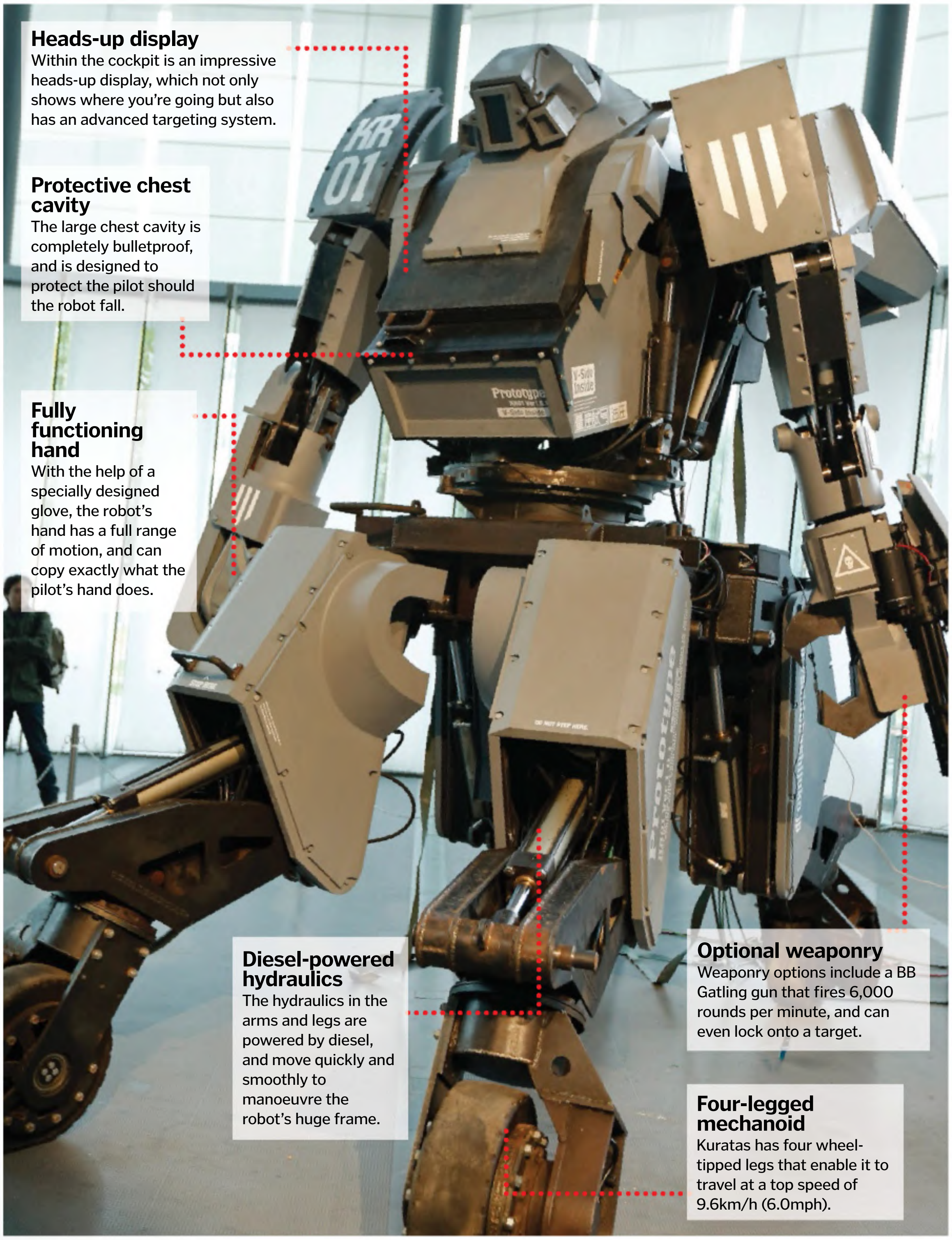
Sphero's designers originally made this awesome little robot from a 3D-printed shell and the electronics from a smartphone. This early concept quickly turned into the real thing, a white robotic orb weighing 730 grams (1.6 pounds), which drives along at 2.1 metres (seven feet) per second thanks to its built-in electric motor. You can drive Sphero with any Bluetooth-enabled smartphone; it can even be used as a controller for certain games on both iOS and Android platforms. The official Sphero app is a nice touch, as it automatically updates the robot's software, keeping your robot bug-free and working at its optimum level. If customisation is your thing, programmable versions are available that allow you to code the robot yourself using a simple coding language. The changeable colour schemes are great when racing a couple of these robots together, particularly when you race at night. Amazingly, Sphero is completely waterproof, and can take on a swimming pool with ease, like a ball-shaped Olympic athlete racing for gold. The Sphero is a brilliant introduction to the world of robotics. If you're not sure if robots are for you, try one of these little chaps; they'll definitely convert you.

5: Kuratas

The closest you can get to Tony Stark's suit, this Japanese super-robot provides you with your own weaponised, armoured suit

Price: *£650,000*
Country of origin: *Japan*
Main function: *Armoured suit*

Kogoro Kurata, a Japanese engineer, always dreamt of seeing the giant robots in the television shows of his childhood come to life. With the help of another roboticist, he built the world's first human-piloted robot – Kuratas. Standing at a towering four metres (13 feet) tall and weighing 4,500 kilograms (9,920 pounds), Kuratas is truly impressive to behold. Unveiled in 2012, it has a host of superb technology, including a fantastic heads-up display in the cockpit and advanced weaponry. One of its most sinister features is the firing system for its 6,000 rounds per minute BB Gatling gun; the pilot can fire simply by smiling. It's run by an intelligent V-Sido operating system, designed by the head roboticist who helped build Kuratas. The software enables the robot to be controlled by an internet-enabled smartphone, a feature known as the 'Master Slave System'. Amazingly, a fully-fledged version of this incredible robot is already available to buy, showing just how far robotics has come in the last 20 years. In 2016, Kuratas is set to fight a similar creation from an American company, Megabots, to see who has created the toughest mechanoid. The American robot is tough, but once you've seen Kuratas it's hard to bet against it.



6: iRobot Roomba 880

This programmable robot vacuum cleaner will clean your floors without the need of human assistance

Price: *£569.99* *Country of origin:* *United States* *Main function:* *Cleaning*

With the Roomba 880, cleaning your own floors becomes a thing of the past. Simply programme in a time and day and the Roomba will trundle off at its own leisure to vacuum all your rooms, returning to its charging base once its battery runs low. Removing tough stains isn't Roomba's thing; it's designed to clean once a day to keep floors clean at all times. It's not cheap, but works out to be less pricey than hiring a human cleaner, and gives you that 'just-vacuumed' feeling without lifting a finger.

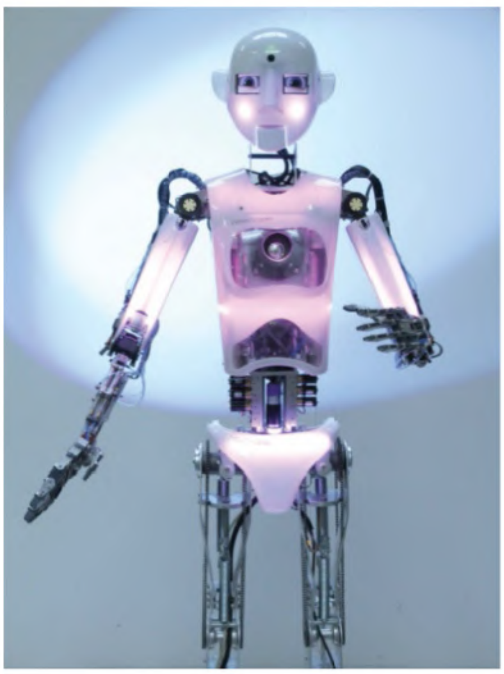
DID YOU KNOW? *In 2014, an estimated 3.3 million household assistance robots were sold worldwide*

7: MOSS Exofabulatronixx 5200

The Exofabulatronixx 5200 is fully customisable, letting you unlock your inner engineer and build your very own robot

Price: £499 *Country of origin:* United States *Main function:* Customisable robot

The clever design behind this robot relies on a block-based construction system. Each block is a different part of the robot and can provide a different function, meaning the more you experiment with the structure, the more you can develop. It's designed to be used by children and adults alike as there is no complex programming required. When you alter the robots structure, it's very much 'plug-and-play'. Whether you want to build your own front-loaded racecar or just experiment, the Exofabulatronixx 5200 is a great introduction to the world of robotics.



8: RoboThespian

Designed to guide museum visitors or to be used in education, RoboThespian is an excellent public speaker who's here to help

Price: £55,000
Country of origin: United Kingdom
Main function: Education

RoboThespian has been under continuous development since 2005. It is primarily a communication robot, which is evident in its impressive ability to gesture and convey emotion. Its eyes are made of LCD screens, which change colour in relation to the robot's movement, and its limbs are driven by changes in air pressure. This allows for precise movement of the robot's hands, helping it to communicate effectively. It can be controlled remotely from any browser, to make sure it's providing the best possible public service.

9: HRP-4

One of the most advanced humanoid robots ever made, the HRP-4 is literally all-singing, all-dancing

Price: £200,000
Country of origin: Japan
Main function: Human assistance

The HRP-4 from Kawada Industries is one of the most advanced humanoid robots ever created. It was designed to work in collaboration with humans, and its high level of intelligence means it could easily integrate into almost any working environment. Each arm has seven degrees of freedom, allowing it to move in any direction it needs, and it can walk like a human, maintaining its balance with ease. The robot is able to converse with humans and understand them. The HRP-4C model is even able to dance and sing!

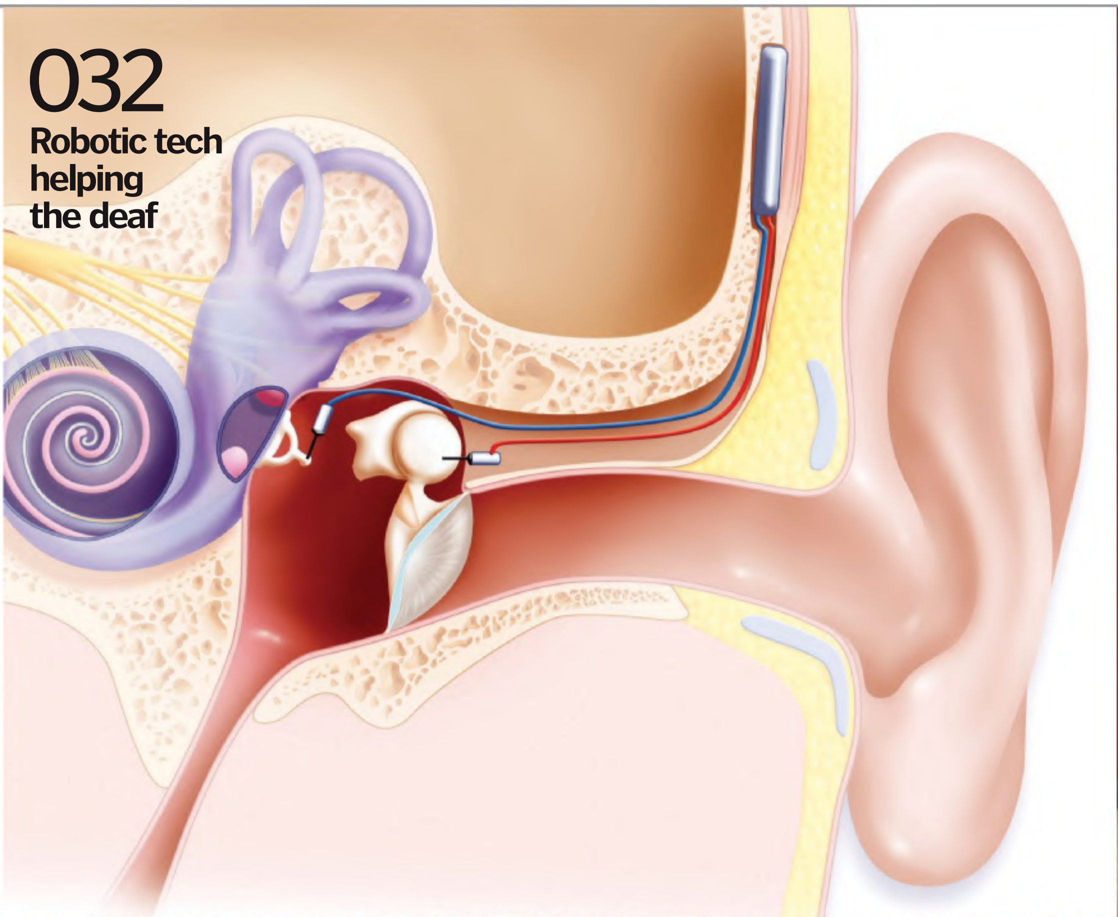
10: Pepper

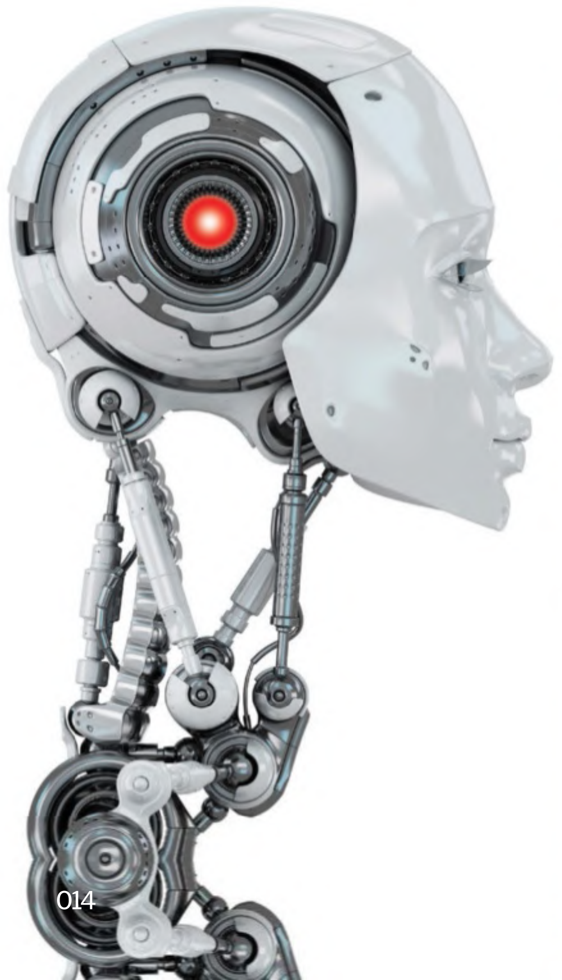
Able to read human emotions and analyse your body language, you can talk to Pepper as if it were a friend or family member

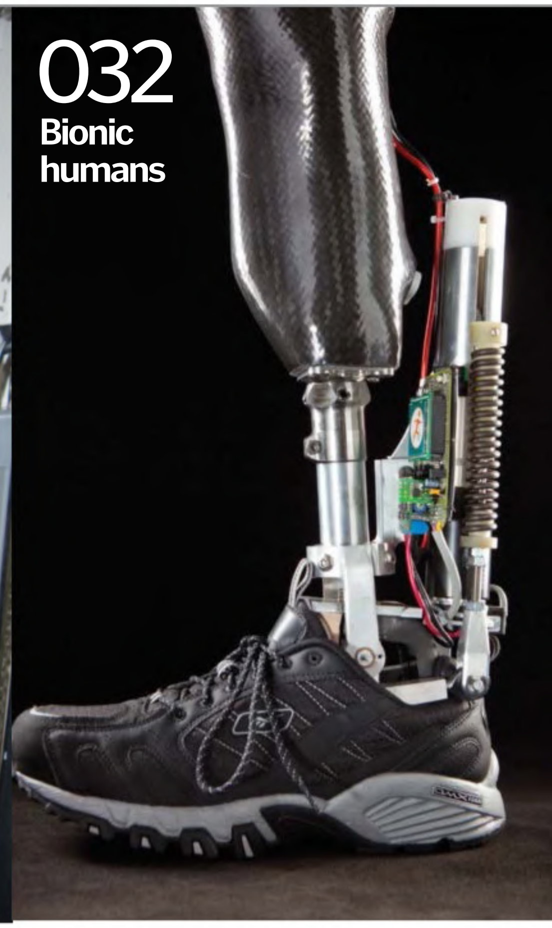
Price: £1,070
Country of origin: Japan
Main function: Household robot

Pepper uses its 'emotional engine' and a cloud-based artificial intelligence system to analyse human gestures, voice tones and expressions, enabling it to read our emotions more effectively than the majority of its contemporaries. Pepper doesn't take up much space, standing at only 58 centimetres (23 inches) tall but doesn't lack in intelligence, speaking 19 languages fluently. 1,000 units of this humanoid sold within a minute of it going on sale, which shows that there is some serious demand for this type of household robot.

HUMANS & ROBOTS







The birth of Robotics

From automated machines to robots with advanced artificial intelligence, the history of robotics dates back hundreds of years and has changed the world we live in

The concept of automated machines has existed for thousands of years, from artificial servants for Gods in Greek mythology to intricate, water-powered astronomical clocks by Chinese inventors in the 11th century. Leonardo da Vinci even designed a range of automata including self-propelled carts and mechanical knights. So when did automated machines become robots?

The modern concept of robotics began during the Industrial Revolution with steam and electricity paving the way for powered motors and machinery. Inventions and discoveries made by Thomas Edison and Nikola Tesla helped usher in a new era of robotics. In 1898, Tesla presented his radio-controlled boat which he boasted was the first in a future race of robots. Many have credited this event as the birth of robotics.

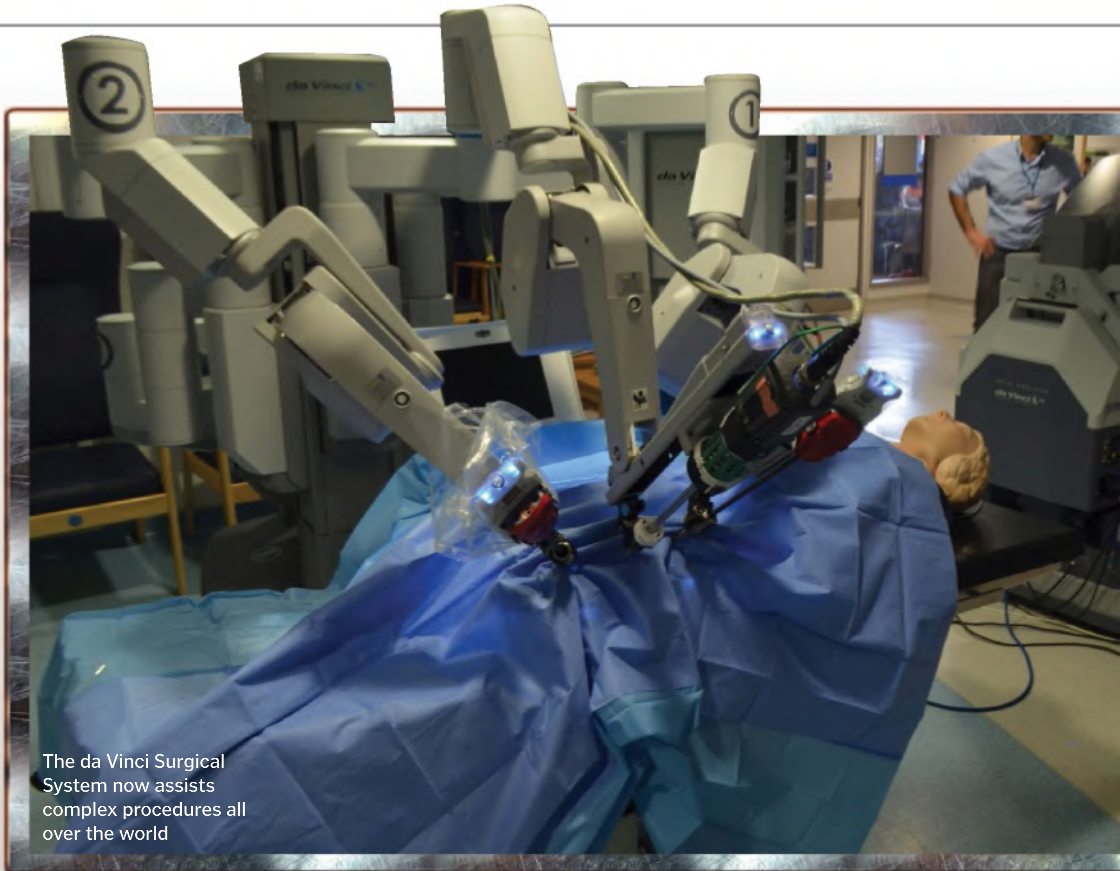
However, the word 'robot' wasn't used until 1921 when Czech playwright Karl Capek wrote *R.U.R (Rossum's Universal Robots)* which told the story of robot factory workers rebelling against their human masters. More famously, science fiction writer Isaac Asimov coined the term 'robotics' in the 1942 short story, *Runabout*. This optimistically characterised robots as helpful servants of mankind. Asimov's three 'Laws of Robotics' continue to influence literature, film and science as our research into artificial intelligence continues.

Key inventions in the 20th century, including the digital computer, transistor and microchip, meant scientists could start developing electronic, programmable brains for robots. Industrial robots are commonplace in the modern factory, used for a range of tasks from transporting materials to assembling parts. Biomedical, manufacturing, transportation, space and defence industries are utilising robots in more ways than ever before.

Significant advancements in software and artificial intelligence (AI) has produced robots like Honda's bipedal ASIMO that mimics the basic form and interaction of humans. IBM's Watson computer has an advanced AI that was originally designed to compete on the American quiz show, *Jeopardy!* – however, the software is now being applied to help diagnose illnesses in the health care sector.

BigDog by Boston Dynamics is a rough-terrain robot capable of carrying heavy loads and is currently being trialled by the US Marines. Modern autopilot systems integrated into aircraft, self-driving cars and even space rovers such as Curiosity currently roaming the surface of Mars demonstrate how sophisticated programmable robots have become.

Robots are no longer the property of Greek myth or Hollywood film. Droids, drones and robots are now a widespread and essential part of our society.



The da Vinci Surgical System now assists complex procedures all over the world

First medical robot

Name: *Arthrobot*

Year: *1983*

Creators: *Dr James McEwen, Geof Auchinlek, Dr Brian Day*

The first documented use of a medical robot occurred in 1984 when the Arthrobot, developed in Vancouver by Dr James McEwen and Geof Auchinlek in collaboration with the surgeon Dr Brian Day, was used as part of an orthopaedic surgical procedure.

The Arthrobot was a small, bone-mountable robot for performing hip arthroplasty (restorative surgery for joints). It was designed for the task of precision drilling in hip surgery and could be programmed with the specific location and trajectory of the cavity it would create to house the hip implants.

Although small and relatively basic, improvements and modifications of the original Arthrobot have led to the use of robots in more complicated surgical procedures, including total knee replacements.

As ground-breaking as the Arthrobot was in the field of medical robotics, it wasn't until 1997 that robots started to enter mainstream medicine. The 'da Vinci Surgical System' by Intuitive Surgical, Inc became the first surgical robot to gain approval by the US Food and Drug Administration. The da Vinci robot is a full surgical system featuring a range of instruments, cameras, sensors and utensils.

"The concept of robotics began during the Industrial Revolution, with steam and electricity paving the way for powered motors"

First military robot

Name: *Teletank*

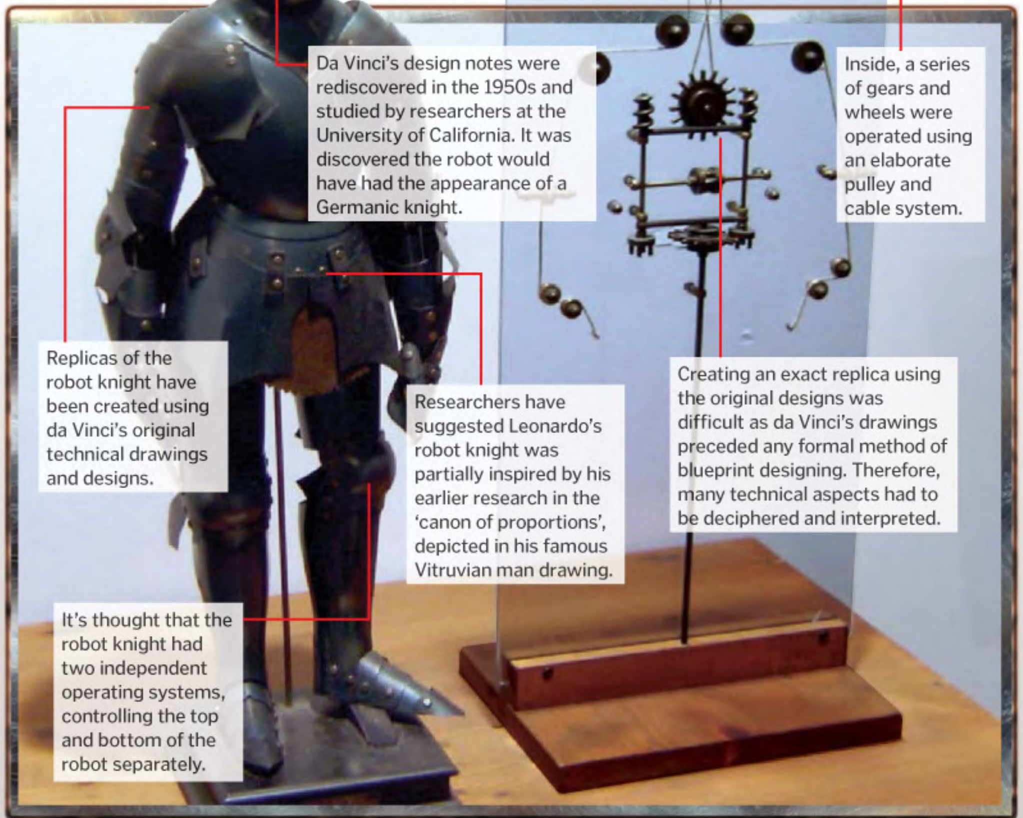
Year: *1930-40*

Creator: *USSR*

Nikola Tesla's invention of the radio-controlled boat in 1898 was intended for military use, but the technology, offered to both the US and UK, was never developed.

World War II saw the first use of military robots in the form of the unmanned and remotely controlled German Goliath tank and the Soviet Teletank. The Teletanks were repurposed T-26 light tanks fitted with hydraulics and wired for radio control. They were equipped with machine guns, flamethrowers and smoke canisters which meant they were a formidable weapon on the battlefield. German Goliaths, on the other hand, were designed as mobile landmines that could be remotely driven up to enemy vehicles or personnel and detonated.

Although the Teletank and Goliath were developed in a similar time period, the Teletank was deployed first during the Winter War of 1939-1940 when the Soviet forces battled Axis forces in Eastern Finland.



First humanoid robot

Name: *Leonardo's Robot Knight*

Year: *1495*

Creator: *Leonardo da Vinci*

A humanoid robot, often referred to as an android in science fiction, is designed to resemble the human form. Basic humanoid automatons have existed for centuries, and have gradually been refined to more closely mimic our appearance and behaviour. One of the first well documented examples is Leonardo da Vinci's mechanical knight.

Leonardo's robot was operated by a series of pulleys and cables that allowed the it to stand, sit and independently move its arms. It had a human form and was even dressed in armour to resemble a knight. Although da Vinci's design is primitive by today's standards, lacking any artificial intelligence or remote control, it was ahead of its time in the 15th century.

Da Vinci employed the use of pulleys, weights and gears in many of his inventions, including his self-propelled cart which many consider to be the first robot. He later went on to design the robot knight for a royal pageant in Milan that took place during the late 1490s.

Da Vinci's drawings for the robot knight are still used as blueprints by modern roboticists, and even helped develop robots for NASA.

Mercedes-Benz has been involved in driverless vehicle research since the 1980s

First robotic transport

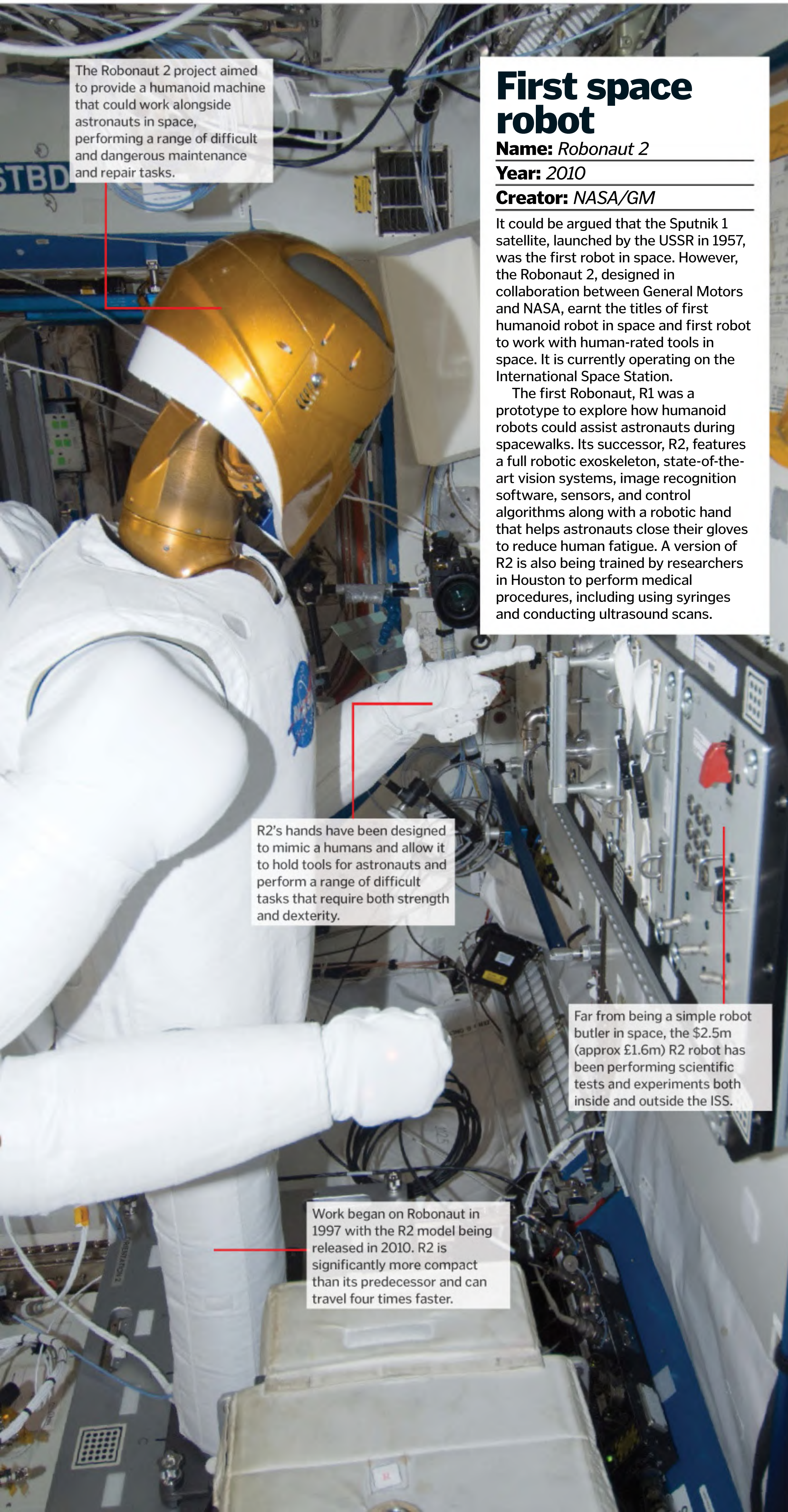
Name: *Eureka PROMETHEUS Project*

Year: *1986*

Creator: *University of Munich/ Mercedes-Benz*

Following the 1964 World's Fair, science fiction writer Isaac Asimov predicted a future where vehicles were driven by "robot brains". For years, autonomous vehicles were limited to theoretical concepts and research projects.

Real progress began in 1986 when the University of Munich launched the Eureka PROMETHEUS Project. For nearly a decade, the team developed a driverless vehicle called VITA, which used sensors to adjust its speed as it detected hazards. In 1994, VITA completed a 1,000-kilometre (620-mile) journey on a highway in heavy Paris traffic, reaching speeds of 128 kilometres (80 miles) per hour. Aspects of VITA were eventually incorporated into new Mercedes-Benz cars.



The Robonaut 2 project aimed to provide a humanoid machine that could work alongside astronauts in space, performing a range of difficult and dangerous maintenance and repair tasks.

R2's hands have been designed to mimic a humans and allow it to hold tools for astronauts and perform a range of difficult tasks that require both strength and dexterity.

Far from being a simple robot butler in space, the $2.5m (approx £1.6m) R2 robot has been performing scientific tests and experiments both inside and outside the ISS.

Work began on Robonaut in 1997 with the R2 model being released in 2010. R2 is significantly more compact than its predecessor and can travel four times faster.

First space robot

Name: *Robonaut 2*

Year: *2010*

Creator: *NASA/GM*

It could be argued that the Sputnik 1 satellite, launched by the USSR in 1957, was the first robot in space. However, the Robonaut 2, designed in collaboration between General Motors and NASA, earnt the titles of first humanoid robot in space and first robot to work with human-rated tools in space. It is currently operating on the International Space Station.

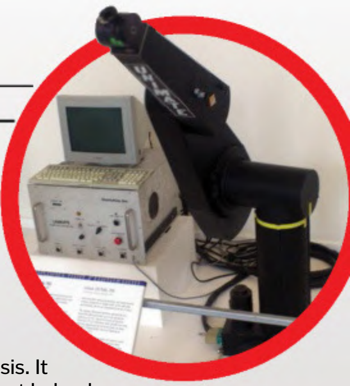
The first Robonaut, R1 was a prototype to explore how humanoid robots could assist astronauts during spacewalks. Its successor, R2, features a full robotic exoskeleton, state-of-the-art vision systems, image recognition software, sensors, and control algorithms along with a robotic hand that helps astronauts close their gloves to reduce human fatigue. A version of R2 is also being trained by researchers in Houston to perform medical procedures, including using syringes and conducting ultrasound scans.

First industrial robot

Name: *Unimate*

Year: *1961*

Creator: *George Devol*



The first industrial robot joined the assembly line at General Motors in 1961. The 'Unimate' used its powerful robot arm to create die castings from machines and welded components onto car chassis. It was the first robotic arm that helped speed up production lines at manufacturing plants around the world.

Originally costing $25,000 (approx £16,200), the robot featured six programmable axes of motion and was designed to handle heavy materials and components at high speed. Using it's 1,800-kilogram (3,970-pound) arm, the Unimate was extremely versatile and soon became one of the most popular industrial robots in the world.

Unimate became popular outside of the manufacturing industry too, appearing on Jonny Carson's *The Tonight Show* where it poured a beer and even conducted an orchestra.

George Devol, who first designed the Unimate in the 1950s, went on to create the world's first robot manufacturing company, Unimation. Robots have become commonplace on the modern assembly line as their ability to perform repetitive tasks at high-speed makes them ideal for manufacturing.

First robot drone

Name: *Tadiran Mastiff III*

Year: *1973*

Creator: *Tadiran Electronic Industries*

Robot drones, or unmanned aerial vehicles (UAVs), have existed for hundreds of years, with the first documented use by the Austrian army, who used balloon bombs to attack Venice in 1849. Military research in the 20th century resulted in a number of technological innovations, including Global Positioning Systems (GPS) and the Internet.

This led to the development of the first, fully autonomous battlefield drone in 1973. The Israeli-made Tadiran Mastiff III featured a data-link system that could automatically feed live, high-resolution video of the target area to its operators. The drone was unmanned, could be pre-programmed with a flight plan and was commonly used by the Israeli Defence Force.

State-of-the-art military drones like the Predator and Taranis play a pivotal role on the modern battlefield.

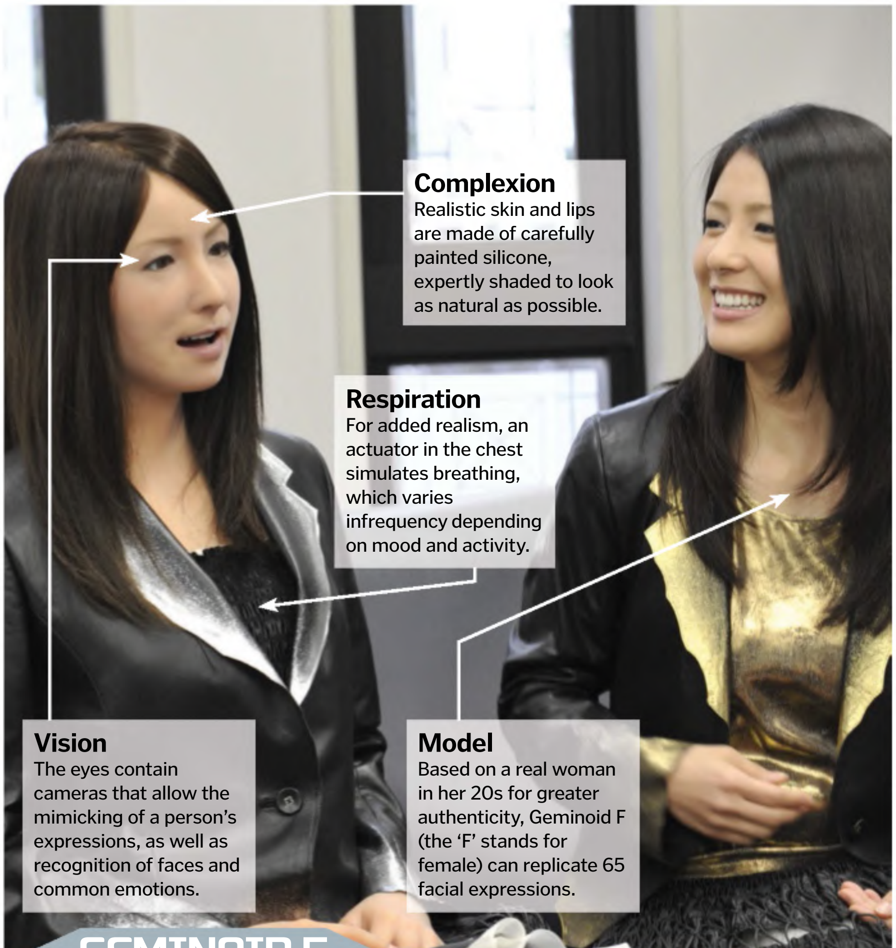
HOW ROBOTS ARE TRANSFORMING OUR WORLD

Do Asimov's laws still apply?

Sci-fi author Isaac Asimov wrote the 'Three Laws of Robotics' in 1942 to govern the direction of his fiction. The first law stated that a robot may not harm a human or allow them to come to harm through inaction. The second was that a robot must obey humans except where the command would violate the first law, and the third was that a robot must protect its existence except where this violates laws one and two. Though these guidelines have achieved a cult-like status, robot ethics have evolved as much as the tech.

Everyone, at some point in their lives, has looked at one robot or another and said "Wow!". Whether it's excitement, enthusiasm, fear or repulsion, there always seems to be an emotional response to the appearance of the latest mechanical being.

Robotic technology has been steadily progressing over the last few decades, and new mechanics and materials are beginning to make it possible for robots to do some quite unbelievable things. Improving strength and reducing weight are two vital requirements of any robotic system as this allows ever-smaller robots to do bigger and better things. Materials such as carbon-fibre composites, advanced metal alloys, extraordinary plastics and modern ceramics make almost any



GEMINOID F

The human impersonator

Meet perhaps the most human-looking machine ever to have been built

- ✓ A convincing human
- ✓ Pop singer replacement
- ✗ Passes the Turing Test

Underneath the realistic silicone skin of the Geminoid F lies the familiar face of a robot. Machined from aluminium, the latest version of this Japanese robot has just one quarter of the hardware used in its predecessor (Geminoid HI-1), with just 12 degrees of freedom. Unlike most modern robots, the Geminoid series doesn't use electric motors for animation. Compressed air and pneumatic rams are used instead, as the creators feel it gives a more human-like quality to their movements. Geminoid F uses an electric air compressor to supply her many actuators. These are controlled by computer-operated valves, in order to reliably synchronise the 65 facial expressions to match the words spoken by the robot. Human head movements, gestures and facial features are observed, recorded by the computer and mimicked to improve realism. Operators can speak via the Geminoid, or have her respond autonomously using a computer program to work out a suitable reply to questions.

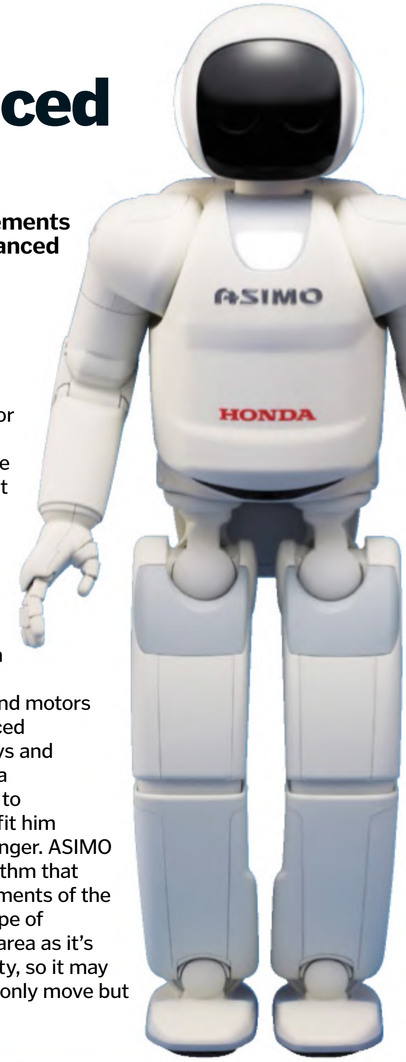
ASIMO

The advanced humanoid

We reveal the latest enhancements to Honda's ever-popular Advanced Step in Innovative Mobility

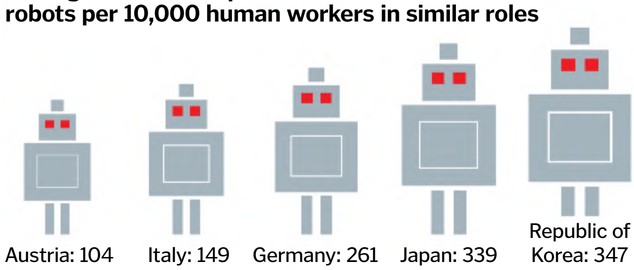
- ✓ Uses sign language
- ✓ Serves you Martinis
- ✓ Plays football

ASIMO has been in development for 26 years. He can now run, jump, climb stairs, make drinks and shake hands, so his physical development is going well. The key to future progress is to take advantage of new tech such as ever-faster processors and the much-anticipated quantum computers. ASIMO uses brushless servomotors that allow a very high degree of motion accuracy. Miniaturisation of the gearboxes and motors has been made possible by advanced materials such as magnesium alloys and neodymium magnets. ASIMO has a magnesium skeleton, but a switch to carbon-fibre composites will benefit him greatly as it's both lighter and stronger. ASIMO relies heavily on a predictive algorithm that anticipates the most likely requirements of the limbs before moving them. This type of pre-emptive control is an exciting area as it's only limited by computing capability, so it may not be long before ASIMO can not only move but also think for himself.



Robot density

The figures below represent the number of industrial robots per 10,000 human workers in similar roles



physical requirement possible, but even newer technologies, such as carbon nanotubes, are promising almost unlimited strength.

The latest advances in brushless motor technology and control, lithium batteries and digital optics open up possibilities that simply have never existed before. These technologies are still quite recent, however, so they have a long process of refinement ahead of them.

Robots are being designed specifically to work with disabled and vulnerable children and adults, following observations that patients responded extraordinarily well to friendly, non-threatening robots, often when human contact had failed. This is amazing as having such emotional bonds with inanimate objects is counterintuitive: what is it about robots that makes them lovable or trustworthy? Extensive research is now underway into therapeutic robotic applications.

What really makes modern robots special, though, is the key element in any automaton: the 'brain'. This has been growing year after year, with computers getting ever-faster and more capable. Modern laptops are powerful enough to run some of the most complex robotic systems, which has made the whole industry accessible to more innovators that stimulate new ideas. We are, however, approaching a key point in history, when computers can't get any faster without a fundamental change in the way they work, and quantum computing will either happen, or it won't. This will be an evolutionary crossroads for robots. They will either get exponentially smarter almost overnight – maybe to the point of being self-aware – or their meteoric rise will suddenly level off and they will remain at their current level of capability, more or less, for the foreseeable future.

It's an exciting time for those interested in these complex machines, as they're so advanced, they surely can't develop at this rate for much longer. The question is, when current materials can get no stronger, and conventional computers can get no faster, will robot development step up to a whole new level, or will it hit a brick wall? Only time will tell.

ROBONAUT 2

The astrobot

The first humanoid robot in space has been lending a helping hand to astronauts on the ISS

- ✓ Goes where astronauts daren't
- ✓ Steady arm
- ✗ Can go for a stroll

The latest version of the Robonaut is an engineering marvel. Not only does he look cool, but he's also leading the way for future robotic systems to work alongside humans in space and industry. The International Space Station (ISS) supplies electricity to the super-advanced computerised control systems stored in Robonaut's torso, which in turn control brushless electric motors. The grease in the motors must be a special compound for fire resistance and to prevent 'out-gassing' in a vacuum. As advanced as he is, it's his personal interaction that's made his case for future development. Working alongside astronauts in the ISS has shown his inductive control system is powerful enough to move huge loads, yet gentle enough that accidental contact will cause no harm. This means that future industrial bots wouldn't need safety screens or emergency stop buttons.

E.ZIGREEN CLASSIC

The gardener

Dodging obstacles and trimming turf with the latest in auto-lawnmowers

- ✓ Cuts grass
- ✓ Avoids gnomes
- ✗ Takes cuttings to the dump

The E.zigreen Classic is a small, autonomous lawnmower that can adapt to its environment using sensors. It knows where the edges of the garden are thanks to limit wires, while ultrasound sensors detect obstacles. The cutting blades and the driving wheels are powered by electric motors and run off rechargeable batteries. A number of failsafe sensors ensure the mower deactivates if anything goes wrong, and it can return to its charging dock by itself.

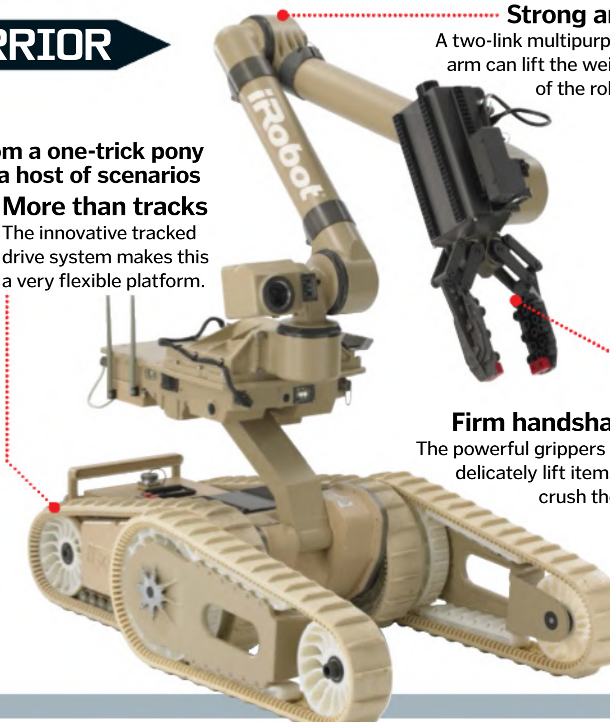
iROBOT 710 WARRIOR

The warrior

This multifunctional robot is far from a one-trick pony with the ability to be fitted out for a host of scenarios

- ✓ Expert at mine excavation
- ✓ Arm-wrestling master
- ✗ Outlasts a fully charged iPhone

The 710 Warrior is a remote-control robot that can climb stairs and perform manoeuvres such as 'standing up' on its innovative tracks. The twin lithium batteries keep the powerful electric drive motors turning for up to ten hours at a time. It can be fitted with robotic arms, sensors or weapons, as well as cameras, data-links and a wireless internet hub to support the information and communication needs of troops and rescue workers. The amazing thing about this robot is that it can adapt to the ever-changing requirements of a mission with upgrades easily bolted on.



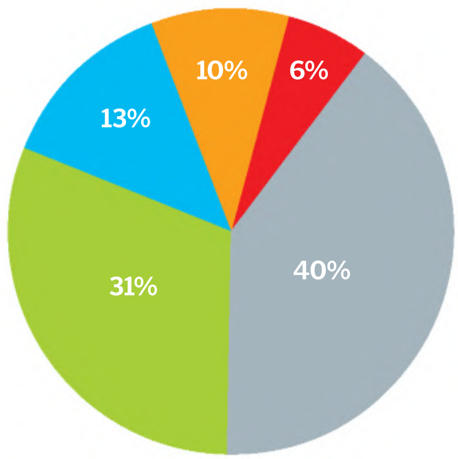
Strong arm
A two-link multipurpose arm can lift the weight of the robot.

More than tracks
The innovative tracked drive system makes this a very flexible platform.

Firm handshake
The powerful grippers can delicately lift items or crush them.

Service robot sales breakdown

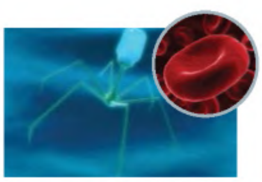
From agriculture to the military, which sector spent the most on service robots in 2011?



Key:
Defence Field Logistics Medical Other
Source: International Federation of Robotics

Sizing up robots

Because they're used for a wide variety of roles, robots come in many different shapes and sizes...



Nanobot
As big as... A blood cell
These chemically powered tiny robots are being developed to locate and even treat cancerous cells.

© Thinkstock

Hummingbird
As big as... A human hand
The Nano Air Vehicle (NAV) has been created for military operations, such as covert surveillance.

© DARPA

HAL robot suit
As big as... A human leg
The Hybrid Assistive Limb (HAL) suit is a robotic exoskeleton designed for rehabilitation after injury.

© Prof Sankai/CYBERDYNE Inc

Curiosity rover
As big as... A small SUV
Currently the all-in-one lab is looking to establish whether life could ever have existed on Mars.

Titan
As big as... A lamppost
Articulated robot arms used in heavy industry are incredibly strong. KUKA's Titan can lift up to a ton!

Robots

38

Percentage increase in sales of robots in 2011 from 2010

ALPHADOG

A soldier's best friend

Get to know the petrol-powered hydraulic pet that can traverse almost any terrain

✓ Faithful canine companion ✓ House-trained ✗ Can be kicked over

Very little captures the imagination more than a fully functioning robotic 'pack horse' that moves just like the real thing. This stunning machine has four legs that are independently controlled by a central computer, using the data from dozens of sensors. The data is continuously translated into navigation and stability requirements. The requirements are then translated into leg and hip movements by a powerful hydraulic system. The screaming petrol engine turns a high-pressure pump to push oil to 16 hydraulic servo actuators (four in each leg) through a network of filters, manifolds, accumulators and valves. This moves each leg quickly and precisely. The advanced stabilisation gyro and accelerometers keep the AlphaDog on its feet through mud, sand, snow and even ice. The technology and techniques developed on the AlphaDog have led to a two-legged version that moves just like a human, which opens up all number of possibilities for the future.

TWENDY-ONE

The butler

This workhorse is perfectly suited to caring for the infirm both in hospitals and the home

✓ Helps the aged
✓ Strong yet sensitive
✓ Can hold a pencil

Twendy-One is designed to offer assistance to the elderly and disabled. Using its innovative harmonic drive motor, Twendy-One is able to lift 35 kilograms (77 pounds). The highly dexterous hands and inductive passive control system ensure it doesn't impact a person or object hard enough to harm them. In order to manoeuvre around bends, Twendy-One rolls around on an omnidirectional wheel-based drive system. The torso also has 12 ultrasonic sensors and padded silicone skin. This robot is designed to look after vulnerable people, so it has a sculpted, curved body and head to appear more friendly.

by numbers

841,000
Estimated number of entertainment robots that were sold in 2011

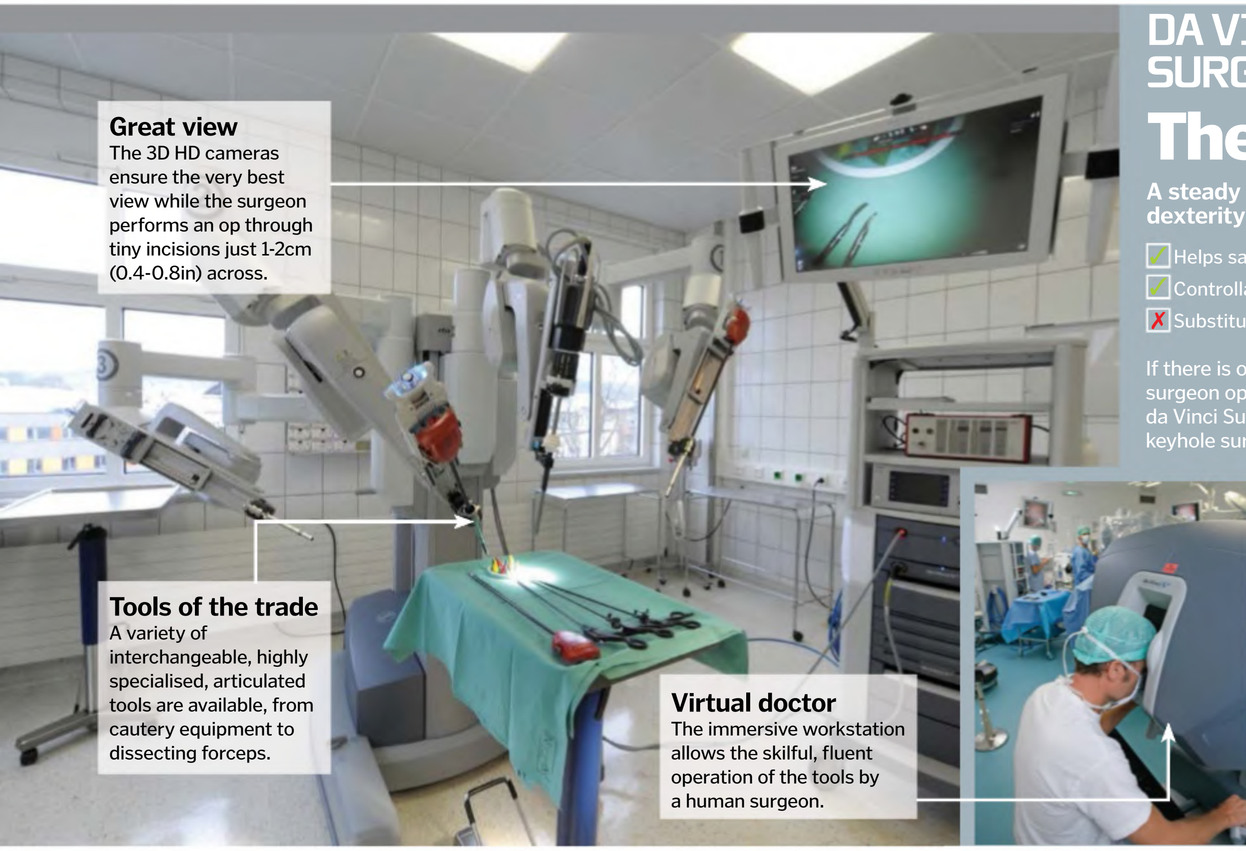
5 **Predicted percentage of average rise in sales of robots per year**

9.8 million
Estimated number of domestic robots that will be sold between 2011 and 2014

25.5 billion
Estimated worldwide market value for robotic systems in 2011 in US dollars

13 **Percentage increase in sales of medical robots in 2011**

40
Percentage of total number of service robots in defence applications



DA VINCI SURGICAL SYSTEM

The surgeon

A steady hand, 3D HD vision and great dexterity make this one smooth operator

- ✓ Helps save lives
- ✓ Controllable over great distances
- ✗ Substitute for medical advice

If there is one person you need to trust, it's the surgeon operating on you or a loved one. Using the da Vinci Surgical System, the patient undergoes keyhole surgery by the robot, but this is controlled by the hand movements of a surgeon sitting in a control booth. These movements are measured and modified to reduce hand tremors or sensitivity, and then performed by the robot, meaning the da Vinci Surgical System is actually better with the tools than the surgeon controlling it. Doctors can conduct operations from a booth anywhere in the world thanks to the 3D high-definition display and cameras, though typically they will be sitting just a few metres away, in case of complications.

PREDATOR MQ-9 REAPER

The aerial assassin

Explore the pilotless vehicle which can soar across enemy lines and take out a target with deadly accuracy

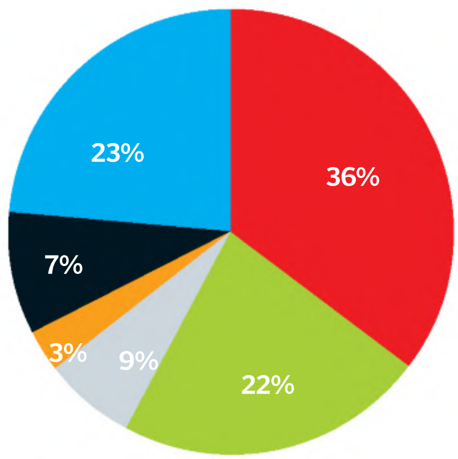
- ✓ Flies autonomously
- ✓ Remotely bombs hostiles
- ✓ Provides real-time intel

This unmanned aerial vehicle (UAV) has proved to be one of the most important military systems in recent years. Having no pilot to worry about, the MQ-9 makes efficient use of the conventional airframe to pack a huge array of sensors, weapons and fuel into a relatively small aircraft. Driven by a 708-kilowatt (950-horsepower) turboprop engine, electrical power is generated to run the on-board sensor and communication array, as well as the electrically actuated flight control surfaces, which are doubled up for redundancy. The UAV can function almost wholly autonomously, with an effective autopilot and auto-land capability, but due to the weapons on board, it's never allowed to attack a target itself. Using a secure satellite communications system thousands of kilometres away, human operators take control – in a similar way to flying a model aircraft – and command the Reaper to deploy its missiles.

The Reaper, formerly known as the Predator B, is made by General Atomics and has a top airspeed of 240 knots (444km/h; 276mph)

Industry robot sales breakdown

Take a quick look at the main areas in which industrial robots were employed in 2011



Key:
Automotive **Electronics** **Chemical, rubber & plastics**
Food & beverage **Metal & machinery** **Other**
Source: International Federation of Robotics

Jobs for the bots

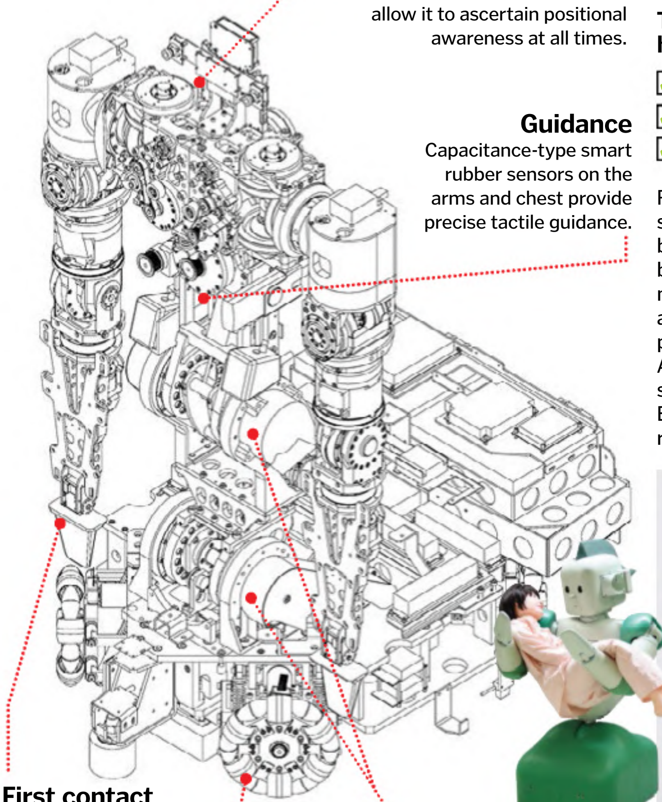
Could that job be carried out by a robot? In

Babysitter

PaPeRo

NEC's PaPeRo robot has many of the abilities of a babysitter. It can tell stories, play games and – most importantly – track the movement of children via its RFID chips.

Inside RIBA-II



Audio and vision
RIBA-II is installed with two cameras and microphones that allow it to ascertain positional awareness at all times.

Guidance
Capacitance-type smart rubber sensors on the arms and chest provide precise tactile guidance.

First contact
Resistance-type sensors in the hands allow it to detect contact with patients or barriers.

Mobility
Four omni-wheels help it to navigate narrow gaps and passages.

Joints
Mechanised joints in the base and lower back enable the robot to crouch down and lift patients even from floor level.

RIBA-II

The lifesaver

This intelligent lifting robot is revolutionising how the convalescing get about in hospital

- ✓ Gets you out of bed in the morning
- ✓ Calculates your weight
- ✓ Features sensors made entirely of rubber

RIBA-II is an electrically powered robotic lifting system designed to reduce injuries in carework. The bear-faced bot safely lifts patients from floor level into bed or onto chairs. His computer and sensors measure the weight and balance of the patient as they are picked up, and RIBA-II calculates the correct positioning of the arms to provide a comfortable lift. Another benefit is the increased dignity offered by such a system, which is very important to patients. Extensive research continues in this exciting area of robot/patient trust and interaction.

RIBA-II is a new-and-improved version of RI-MAN (the green robot just above) with a far greater range of capabilities

E.ZICLEAN WINDORO

The window cleaner

The bot offering a window into the future of domestic help

✓ Perfectionist ✓ Good sticking power ✓ Can be remote controlled

The Windoro is an autonomous window cleaner, similar in concept to the robot vacuum cleaner. The primary unit operates on the inside of the glass, and contains the electric motors, gears and wheels that drive it around the window. Scrubbing the glass with rotating brushes, the electronics send power to the two drive motors to make it follow a pre-programmed pattern that doesn't miss a spot. The slave unit is towed around on the outside using powerful neodymium magnets that also hold both parts tightly against the smooth surface, just like a giant magnetic fish-tank cleaner.

Magnets
Neodymium magnets mean the Windoro will stay in place on the window even when the batteries run out.

Smart
It autonomously measures the window and works out the best pattern for cleaning all of the glass.

Reservoir
An integral water tank in each unit holds the cleaning fluid and water, for a streak-free finish.

The best of the rest…

1 Kod*lab 'cat-bot'
To avoid getting stuck on its back, this modified version of the X-RHex has a swinging counterweight, used as a precisely controlled tail to orientate the body so that it always lands on its feet.

2 USC BioTac
This clever robo-finger mimics human fingerprints to generate a measurable vibration that is different for every texture. It builds up a database of tested materials.

3 Superhydrophonic bot (Harbin Institute)
Ideal for reconnaissance, water content measurement and wildlife research, this tiny bot can walk on water by exploiting surface tension.

4 BD SandFlea
This wheeled robot looks quite conventional, until it reaches a wall. Pointing itself upwards, the computer calculates the angle and power required before leaping up to eight metres (26 feet) into the air.

5 Kuratas
This four-metre (13.2-foot) monster is for one purpose only: to show off. Bottle rocket launchers and twin BB guns will get everybody's attention as you sit behind the full-colour display to control it.

© General Atomics; RIKEN; Kod*lab, University of Pennsylvania; Boston Dynamics; E.zicom Robotics

which vocations are humans being replaced by bots?

© Corbis

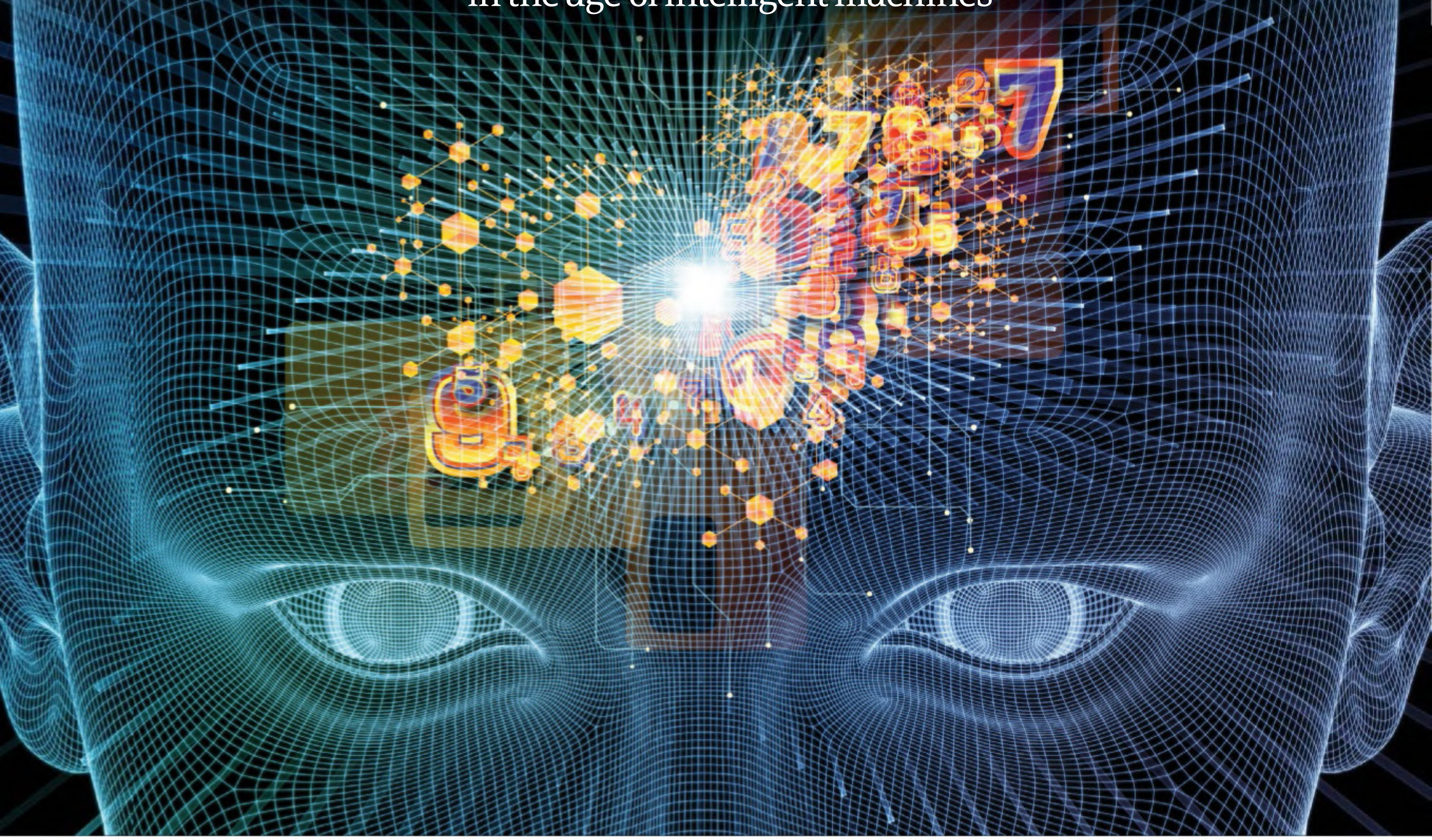
Pharmacist
UCSF Medical Center
The UCSF Medical Center has a robotics-controlled pharmacy that can pick, package and dispense pills. The system has so far prepared in excess of 350,000 prescriptions.

© Claudia Heinstein

Cabbie
Autonomous driverless car
Self-driving cars are a tempting option for taxi companies with their low fuel costs and insurance policies, if they're ever legalised.

ARTIFICIAL INTELLIGENCE

From autonomous vehicles to data mining, we are living in the age of intelligent machines



What is artificial inteligance?" you ask Google. To which it replies, "Did you mean artificial intelligence?" Of course you did. Meanwhile, in the 0.15 seconds it took you to realise your own stupidity, an intelligent machine has assembled 17,900,000 results for your consideration – including video, audio, historical records and the latest headlines – ordered by relevance and reliability. 20 years ago, this type of artificial intelligence would have been the stuff of science fiction, but now we simply call it 'technology'.

Artificial intelligence began over 60 years ago as a philosophical question posed by the brilliant English mathematician Alan Turing: "Can machines think?" In 1955, the words 'artificial intelligence' first appeared in print in a proposal for a summer academic conference to study the hypothesis that "every aspect of learning or other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it".

At its core, the science of AI is the quest to understand the very mechanisms of intelligence. Intelligence in humans or machines can be defined as the ability to solve problems and achieve goals. Computers, it turns out, are the ideal machines for the study of AI, because they are highly 'teachable'. For half a century, researchers have studied cognitive psychology – how humans think – and attempted to write distinct mathematical formulas, or algorithms, that mimic the logical mechanisms of human intelligence.

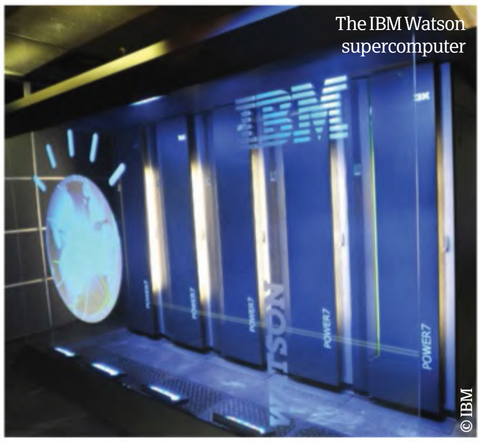
Machines have proven extraordinarily intelligent, with highly logical problems requiring huge numbers of calculations. Consider Deep Blue, the chess-playing computer from IBM that beat grandmaster Gary Kasparov using its brute processing strength to calculate a nearly infinite number of possible moves and countermoves.

Alternatively, consider the everyday examples of astonishing AI, like the GPS navigation systems that come standard in many new cars. Speak the address of your

DID YOU KNOW? *Colossus, the first electronic computer, was built in 1943 by British engineers to crack coded Nazi transmissions*

IBM's Watson

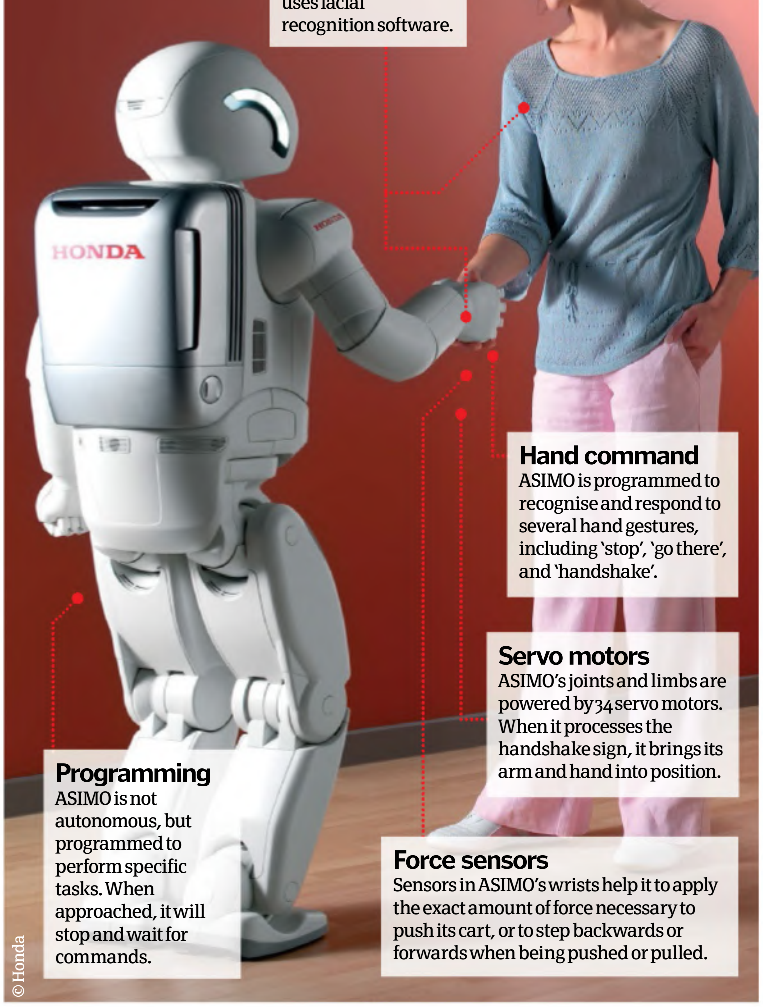
In February 2011, an IBM supercomputer named Watson trounced two previous champions of the US trivia quiz show *Jeopardy!*. Watson parsed natural language questions fast enough to beat the quickest human minds. IBM researchers preloaded the computer with hundreds of millions of pages of data, then armed it with algorithms for searching and 'reading' text – separating subjects, verbs and objects. But this was much more than a super-powered Google search. Watson used advanced algorithms to 'reason' which of its millions of hypothetical answers was most likely to be true. The 'face' behind the *Jeopardy!* podium was backed by a roomful of servers, comparing results in fractions of a second until the computer had enough statistical confidence to buzz in. Watson technology is already being considered as the brains behind an automated physician's assistant.



The IBM Watson supercomputer

© IBM

Shaking hands with ASIMO



Recognition
Using head-mounted cameras and radio sensors, ASIMO can read data on magnetic ID cards in its vicinity. It also uses facial recognition software.

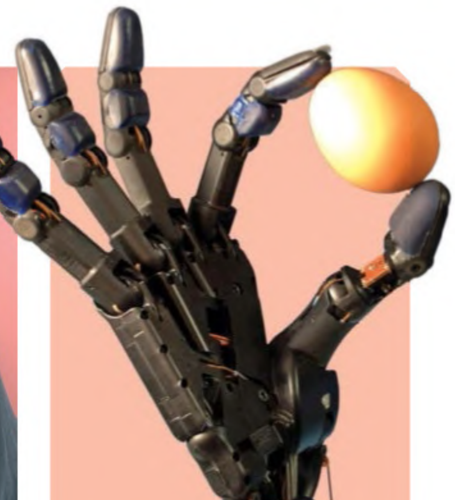
Hand command
ASIMO is programmed to recognise and respond to several hand gestures, including 'stop', 'go there', and 'handshake'.

Servo motors
ASIMO's joints and limbs are powered by 34 servo motors. When it processes the handshake sign, it brings its arm and hand into position.

Programming
ASIMO is not autonomous, but programmed to perform specific tasks. When approached, it will stop and wait for commands.

Force sensors
Sensors in ASIMO's wrists help it to apply the exact amount of force necessary to push its cart, or to step backwards or forwards when being pushed or pulled.

© Honda



Robotics and AI

The world's most advanced robots navigate their environments with sensors that mimic our senses of vision, hearing, touch and balance.

The lifelike androids designed by Hiroshi Ishiguro at the Intelligent Robots Laboratory use real-time facial recognition software to mimic the facial movements of the 'controller'.

Walking robots like ASIMO are equipped with an internal gyroscope and speed sensor to help it maintain balance, even when shoved. Infrared and ultrasonic sensors are used to gauge the distance of the floor and the speed and path of approaching objects. Sensors in hands and feet help it 'feel' the six axes of force – up/down, left/right, forwards/backwards – and the degree of force applied.

destination and the on-board computer will interpret your voice, locate your precise location on the globe and give you detailed directions from Moscow to Madrid. Or even something as 'simple' as the spell check on your word processor, casually fixing your typos as you go.

And then there are AI machines that go far beyond the everyday, like robots. Today's most extraordinary robotic machines are much more than logically intelligent; they're also physically intelligent. Consider Stanley, the 100% autonomous vehicle that barrelled through the Mojave Desert to win the 2005 DARPA Grand Challenge. Stanley used GPS data to pinpoint its location, as well as laser-guided radar and video cameras to scan the distance for obstacles in real-time. Internal gyroscopes and inertial sensors feed constant streams of data into the on-board computer to control steering and acceleration.

The Honda ASIMO (Advanced Step in Innovative MObility) robot grabbed the world's attention with its human-like walk, a feat of intelligent engineering. ASIMO uses infrared and ultrasonic sensors to gauge distances from floors, walls and moving objects, and constantly adjusts its balance and motion with 34 high-precision servo motors. ASIMO's processors are so lightning-fast, you can shove the robot sideways in mid-stride and it will 'instinctively' throw its weight onto an outside foot to right itself. Perhaps the greatest achievements of artificial intelligence over the past half-century have been illustrated by the way that machines can intelligently process information. Google is just one example of intelligent information technology ►

AI FIRSTS
Where artificial intelligence all began and where it's heading next…

5TH CENTURY BCE
Aristotle's logic
Aristotle defines syllogistic logic – how a single conclusion is drawn from two premises.

400 BCE
Mechanical dove
Archytas of Tarentum constructs a wooden dove that can flap its wings and even fly.

13TH CENTURY
Lullian machine
A Spanish monk creates a machine that draws conclusions from different paired symbols.

15TH CENTURY
Spring-driven clocks
These clocks and watches are the world's first mechanical measuring machines.

1642
Pascal's calculating machine
The wooden box with a metal crank can handle both addition and subtraction.

1801
Punch cards
A French silk weaver automatically controls a loom using a series of punch cards.

that can parse obscene amounts of data into useful information. Intelligent cell phone networks bounce packets of voice data along the most efficient path. Logistics software is the engine of global business, calculating the most efficient and profitable way to procure supplies, manufacturer and ship products around the world.

Credit card companies use intelligent software to analyse the buying patterns of millions of cardholders and identify the subtle red flags that signal fraud or theft. In the information age, we rely on these intelligent machines to make sense of streams of seemingly random data.

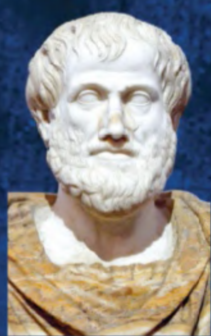
As processing power continues to multiply, we are coming closer to answering Turing's original question: "Can machines think?" We are teaching machines to rely less on pure logic and more on probabilities and experience, what we might call 'intuition'. They are able to pick things up quickly too!

ASIMO uses complex tech to help it maintain balance

© Honda

INSIDE THE AI BRAIN

The human brain is a profoundly complex machine. What we regard as simple common sense is actually a combination of stored knowledge, logical reasoning, probability and language interpretation. In the last 50 years, AI researchers have made strides towards building a machine that can truly 'think'



LOGIC

Dating back to the days of Aristotle, philosophers have attempted to map and define the logical processes by which we make decisions. Rather than living life on a whim, the 'rational actor' makes choices and takes action based on evidence and inference, cause and effect. If a machine is to become a rational actor, it must be programmed to recognise that if A and B are true, then the only logical conclusion is C. The challenge of AI is to create mathematical models for logical processes that the machine can use to make reasonable decisions based on evidence and probability.

LANGUAGE

© IBM

Human beings have many ways of learning, such as listening, watching, reading and feeling. The only way for a machine to learn is through language. Computer programming languages are grounded in logic. Consider the most basic if/then statement: If X is greater than 1, then go to Y. With greater processing power, computers are being taught to interpret natural language – the way humans communicate. IBM's Watson computer can read natural text because it was programmed to parse sentences for subject, verb and object and compare those entries with its vast database of knowledge.

SEARCH AND OPTIMISATION

Google is an example of artificial intelligence – if it was only a search engine, it would randomly assemble a list of every webpage that included your term. But Google programmers have armed the engine with algorithms that help it optimise searches to retrieve the most relevant matches first. AI machines use the same methods to search for the most logical response to environmental data (don't run into that table) or direct queries (what's the balance on my bank account?). They're programmed to use heuristics – short cuts – to eliminate the least-probable search paths.

Google

1821 — Difference Engine No 1
Charles Babbage envisages a complex calculating machine.

1850s — Boolean algebras
George Boole uses syllogistic logic to reduce maths functions to two symbols: 0 and 1.

1889 — Electric tabulating system
Herman Hollerith devises a way to mechanically record data.

1910 — Principia Mathematica
Work the first to derive mathematical truths from a set of axioms using symbolic logic.

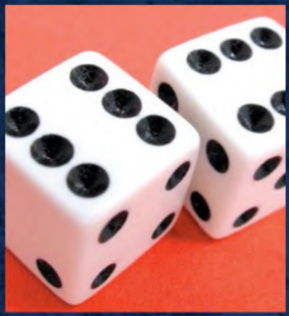
1921 — 'Robot' coined
Sci-fi play is the first to call automatons 'roboti', Czech for 'forced labourers'.

1936 — Turing machine
Polymath Turing describes his 'machine', a theoretical device that establishes the logical foundation for computer science.

1943 — Cybernetics
Studies help to understand machine learning.

PROBABILITY

Humans are likely to base decisions on the probability of something being true, given past experiences and the current conditions. AI machines can be programmed to reason in similar ways. Computers are excellent statisticians, and with the right algorithms, they can quickly make billions of calculations to decide which answer/action is most likely to produce the desired result. As new evidence is presented, AI machines use Bayesian probability to overlap the new set of probabilities over existing calculations.



ALGORITHMS

Algorithms are the bits of programming logic that instruct the computer how to do something. A good example is the minimax algorithm that helps a chess-playing computer like IBM's Deep Blue decide its next move. Minimax algorithms assign a value to each position and piece on the board and search through all possible moves to decide which delivers the best results. To optimise the search, Deep Blue only considered the next 12 moves instead of every possible move and countermove, until checkmate.

REASONING

It was once believed that the AI brain could only reason according to strict rules of logic. Question-answering computers like IBM's Watson are proof that machines can be taught to reason on higher levels. Watson begins with straight logic: searching its vast database of knowledge for keywords in the question. But then it uses much more complex algorithms to identify related concepts and make the kind of intuitive connections we call 'experience'. Probability is a huge component of higher-level machine reasoning, using unprecedented processing power to give the most likely answer from a nearly limitless range of knowledge.

How human are you?

Alan Turing was a British mathematician and philosopher who is considered by many to be the father of AI and modern computer science. In his 1950s paper Computing Machinery And Intelligence, Turing posed the question "Can machines think?" Admitting that 'thought' is such a vague and subjective term, he decided to answer a different question: "Can a machine successfully imitate the way humans interact?" He proposed a game or 'test' in which subject A was human, subject B was a machine and subject C – another human – had to distinguish between the two using text-based questions and answers. Turing himself believed that with enough storage capacity and processing power, a machine could successfully beat the test. This Holy Grail of AI is being pursued by designers of interactive 'virtual assistants' and question-answering supercomputers.

Shown below are answers from the Loebner Prize, an annual competition to determine how human a program can be. In terms of conversation, we clearly still have a little way to go…

Question	ROBOT ANSWER	HUMAN ANSWER
Do you like baseball?	What is a baseball team?	Yes!
When were you born?	I have been born?	1978
What kind of food do you like?	Well, what kind of band is it?	I'm partial to anything, really
Have I offended you?	I just met you. It's kind of hard to develop love	No, not at all!
What is your favourite book?	Led Zeppelin	Lord Of The Flies

1949 – Computer chess
Claude Shannon proposes the functions for programming a computer to play chess.

1955 – 'Artificial intelligence' invented
John McCarthy uses the phrase in a proposal for a conference on machine learning.

1956 – First AI program
The Logic Theorist is the first program written to mimic the human thought process.

1979 – Autonomous robot
The Stanford Cart successfully navigates a room full of obstacles using sensors and software.

1997 – Deep Blue
World chess champion Gary Kasparov loses to the IBM supercomputer.

1997 – Google
The web's most influential piece of AI programming is launched.

2011 – IBM Watson
The DeepQA supercomputer uses language analysis algorithms to beat two former *Jeopardy!* champions.

Robotic surgery

Medical technology in the operating theatre has come on leaps and bounds, but it still needs a helping hand from humans…

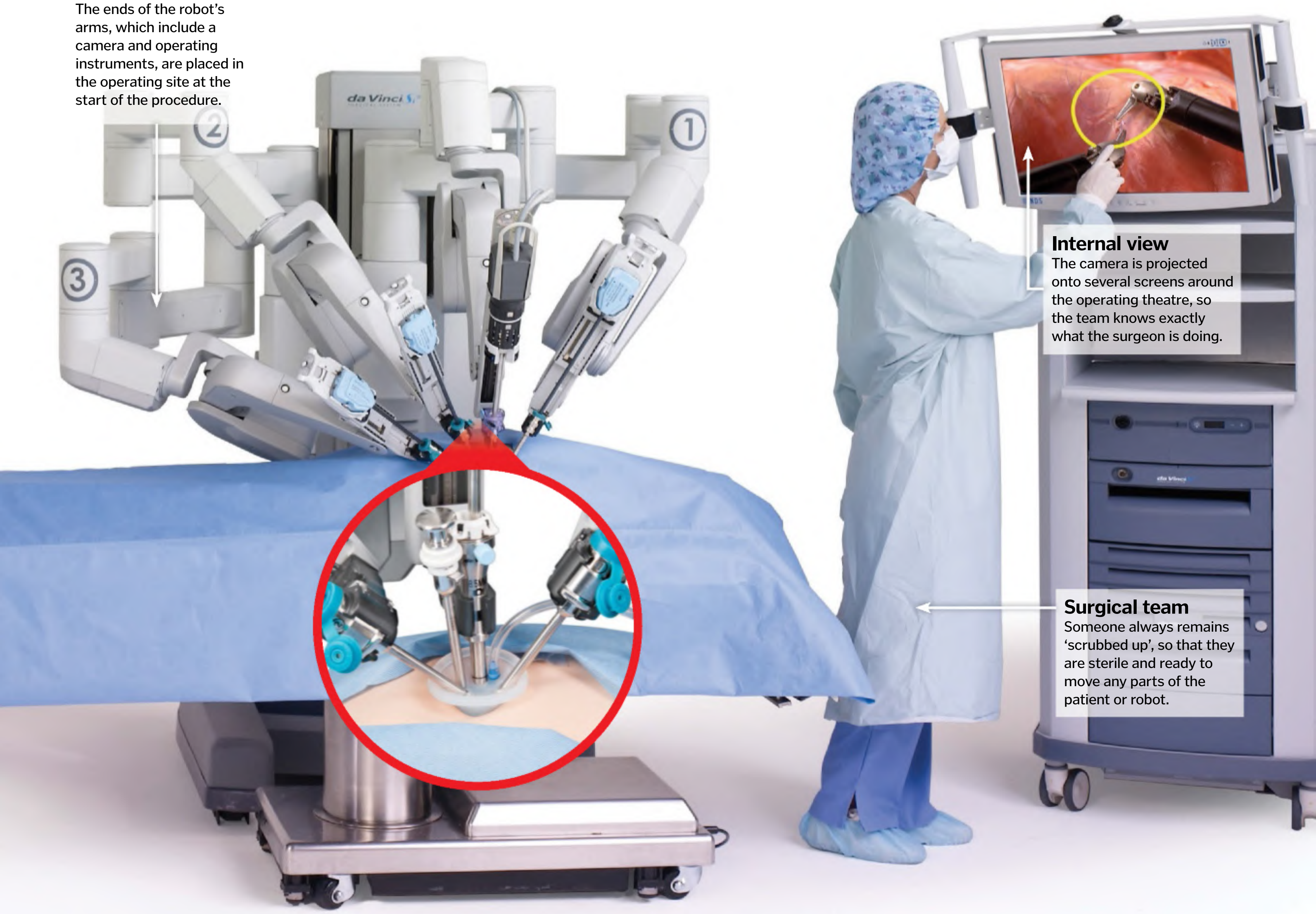
Robotic surgery allows for control and precision previously unknown to surgeons. Contrary to popular belief, the robot does not operate on the patient alone. It is a 'slave' to a human 'master', meaning it is not a true robot (these have intelligence and react automatically). The surgeon sits at a console next to the operating table and the robot is placed around the anaesthetised patient. The surgeon looks at a high-definition 3D image provided by the robot's cameras, and special joysticks are used to control the ultra-fine movements of the robotic arms.

This brings many exciting advantages. The camera, previously held by a human being, is now held perfectly still by the robot. The movements and angles that the arms of the machine provide allow for fine precision and less damage to adjacent tissues when cutting, leading to reduced pain and a faster recovery. This has led to very rapid uptake by some specialists, including urologists (who operate on the bladder and kidney), gynaecologists (who operate on the uterus and ovaries) and heart surgeons. As with most technologies, there are downsides to using robots in operations. They are expensive, large, cumbersome to move into place, and remove the important tactile feeling of real tissue between the surgeon's fingers.

Robotic surgery is considered a step forward from standard keyhole surgery, where the surgeon holds the camera and operating arms. However, early results have shown that there are practically no outcome differences between the two techniques. Combined with higher costs, some surgeons think this means robots are actually inferior to current techniques. This has led to the development of on-going trials, comparing robotic to standard keyhole surgery. Surgeons around the world are working as a single, giant team to deliver these, and the results will determine the future of medical robots for generations to come.

da Vinci in action

This state-of-the-art surgical system works as part of a big team to deliver high-precision surgery. Find out what role it plays now…



Robotic arms
The ends of the robot's arms, which include a camera and operating instruments, are placed in the operating site at the start of the procedure.

Internal view
The camera is projected onto several screens around the operating theatre, so the team knows exactly what the surgeon is doing.

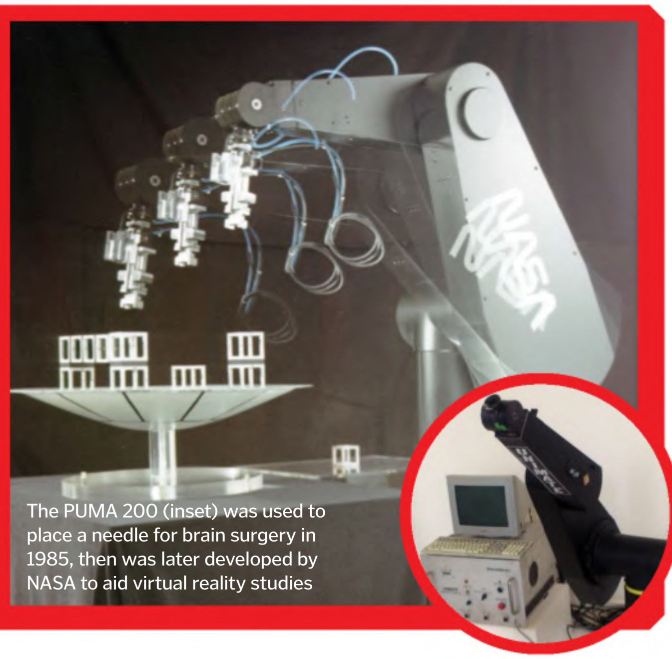
Surgical team
Someone always remains 'scrubbed up', so that they are sterile and ready to move any parts of the patient or robot.

Fluorescence imaging

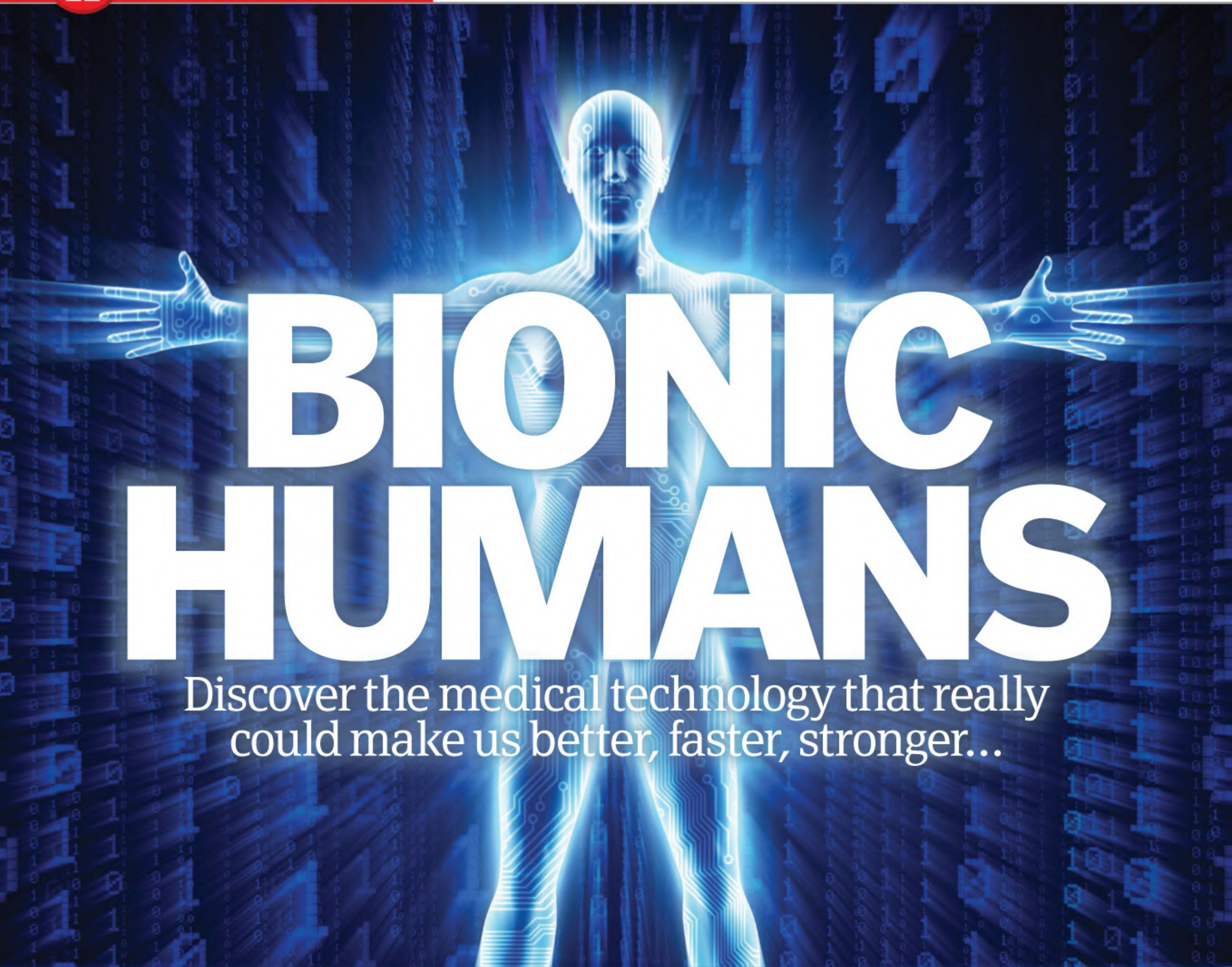
Fluorescence imaging is still in the experimental stages, and is right at the cutting edge of technological science. Indocyanine green (ICG) is a dye that was initially developed for photography and is now used clinically. It is injected into the patient's bloodstream, and has been adapted so that it sticks to cancer cells – for example, within the bowels. At the time of surgery, the doctor inserts a camera into the patient's body (either using their hands or a robot), and the dye is excited by light at a precisely matching wavelength. This creates bright green fluorescence, distinguishing cancerous from normal tissue and allowing the surgeon to make precise incisions.

The evolution of robotic surgery

The current robots in use, like the da Vinci Surgical System, are second generation. The first generation, like the Unimation PUMA developed in the Eighties, had very limited movements and could only carry out specific tasks. The second generation brought a range of fine and varied actions, which surgeons rapidly adapted to. These new-and-improved robots were pioneered and driven forward by North American health systems. Uptake has been slower in Britain due to health budgets, at a time when other treatments have an even bigger impact on patient outcome. There is excitement over development of the third generation of robot, which promises to be more compact, faster and to be packing in even more cutting-edge technology. The future may see telesurgery, where the surgeon in one place (eg a hospital) performs robotic surgery on a patient elsewhere (eg an injured soldier on a battlefield).



The PUMA 200 (inset) was used to place a needle for brain surgery in 1985, then was later developed by NASA to aid virtual reality studies



BIONIC HUMANS

Discover the medical technology that really could make us better, faster, stronger…

Bionics experts attempt to build mechanical and electronic devices to mimic biological functions. With the exception of the brain, the human body can essentially be broken down and rebuilt using a combination of mechanical, electronic and biological technologies.

A bionic limb strips human biology back to its constituent parts. Tough materials like aluminium and carbon fibre replace the skeleton, motors and hydraulics move the limb, while springs replace the tendons that store and release elastic energy. A computer controls motion and wires relay electrical signals, as nerves would have done in a real limb. Users are now even able to control these limbs with their minds (see 'The power of thought').

Technology is also in development to replace individual muscles and tendons following injury. The synthetic muscles are made from a polymer gel, which expands and contracts in response to electrical currents, much like human muscle. The tendons are made from fine synthetic fibres designed to imitate the behaviour of connective tissue.

The mechanical nature of limbs makes them excellent candidates for building robotic counterparts, and the same applies to the human heart. The two ventricles, which supply blood to the body and lungs, are replaced with hydraulically powered chambers. However, it's not just the mechanical components of the human body that can be replaced; as time goes on, even parts of the complex sensory system can be re-created with technology.

Cochlear implants, for example, use a microphone to replace the ear, while retinal implants use a video camera to stand in for the human eye. The data that they capture is then processed and transformed into electrical impulses, which are delivered to the auditory or optic nerve, respectively, and then on to the brain. Bionic touch sensors are also in development. For example, the University of California, Berkeley, is developing 'eSkin' – a network of pressure sensors in a plastic web. This could even allow people to sense touch through their bionic limbs.

Replacing entire organs is one of the ongoing goals of bionic research. However, breaking each organ down and re-creating all of its specialised biological functions is challenging.

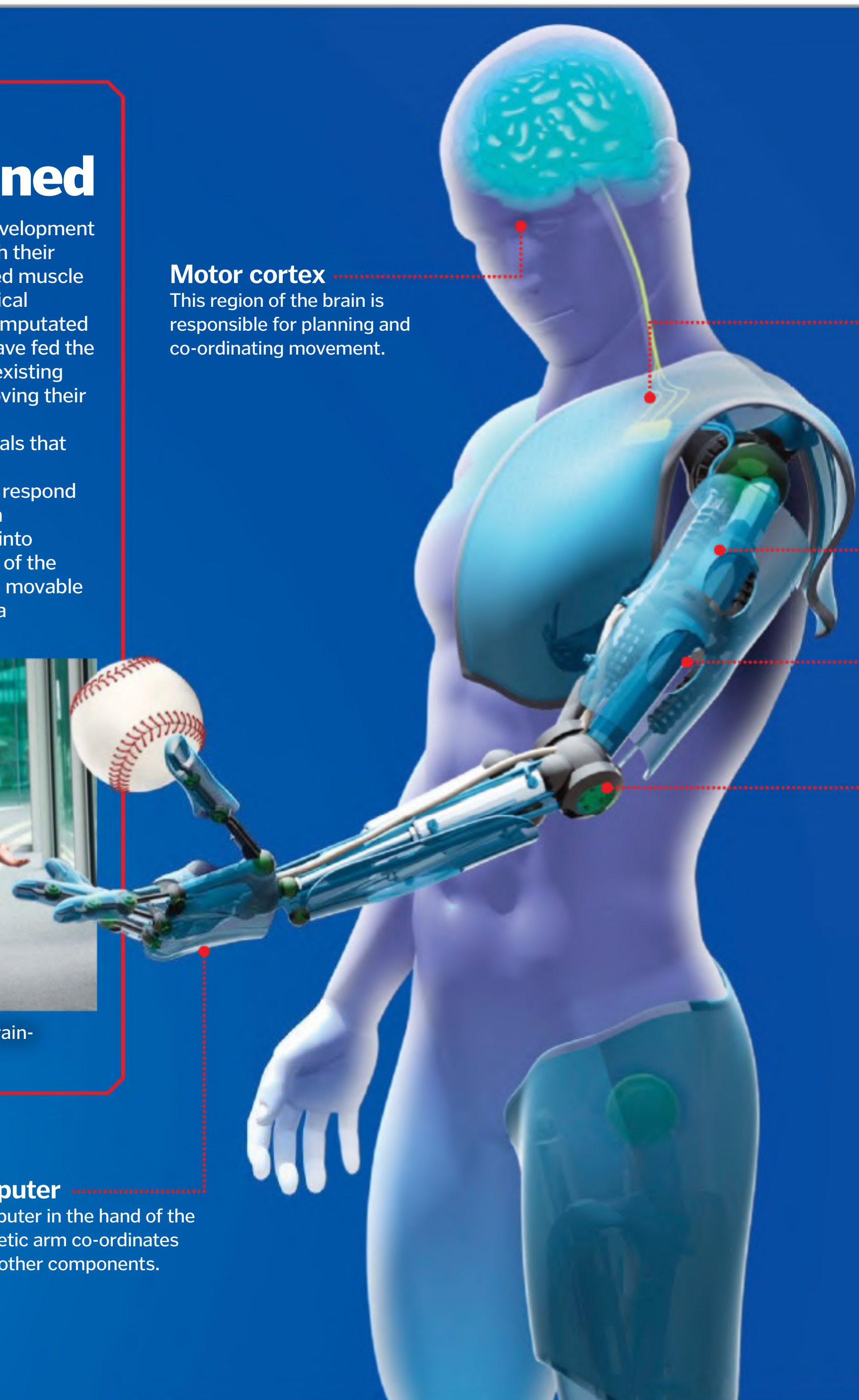
If only part of an organ is damaged, it's simpler to replace the loss of function using bionics. In type 1 diabetes, the insulin-producing beta cells of the pancreas are destroyed by the immune system. Some

The power of thought explained

Cutting-edge bionic limbs currently in development allow the user to control movements with their own thoughts. Technically called 'targeted muscle reinnervation' it's a groundbreaking surgical technique that rewires the nerves in an amputated limb. The remaining nerves that would have fed the missing arm and hand are rerouted into existing muscles. When the user thinks about moving their fingers, the muscles contract, and these contractions generate tiny electrical signals that can be picked up by the prosthetic.

The prosthetic is then programmed to respond to these muscle movements, taking each combination of signals and translating it into mechanical movement of the arm. Some of the most sophisticated have 100 sensors, 26 movable joints and 17 motors, all co-ordinated by a computer built into the prosthetic hand.

A scientist controls a wheelchair using a brain-machine interface



patients are now fitted with an artificial pancreas: a computer worn externally, which monitors blood sugar and administers the correct dose of insulin as required.

Entire organ replacements are much more complicated, and scientists are turning back to biology to manufacture artificial organs. By combining 3D printing with stem cell research, we are now able to print cells layer by layer and build up tissues. In the future, this could lead to customised organ transplants made from the recipient's very own cells.

Advances in bionics mean that already limbs are emerging that exceed human capabilities for weight bearing and speed. That said, the sheer complexity of our internal organs and how they interact means that it is not yet possible to fully replace man with machine. But maybe it's just a matter of time...

The right materials

One of the most important factors in biomedical engineering is biocompatibility – the interaction of different materials with biological tissues.

Implanted materials are often chosen because they are 'biologically inert' and as a result they don't provoke an immune response. These can include titanium, silicone and plastics like PTFE. Artificial heart valves are often coated in a layer of mesh-like fabric made from the same plastic used for soft drink bottles – Dacron. In a biological context, the plastic mesh serves as an inert scaffold, allowing the tissue to grow over the valve, securing it in place. Some scaffolds used in implants are even biodegradable, providing temporary support to the growing tissue, before harmlessly dissolving into the body.

Bionic limbs are worn externally, so their materials are chosen for strength and flexibility as opposed to biocompatibility. Aluminium, carbon fibre and titanium are all used as structural components, providing huge mechanical strength.

Artificial heart valves are often made from metal, such as titanium or stainless steel

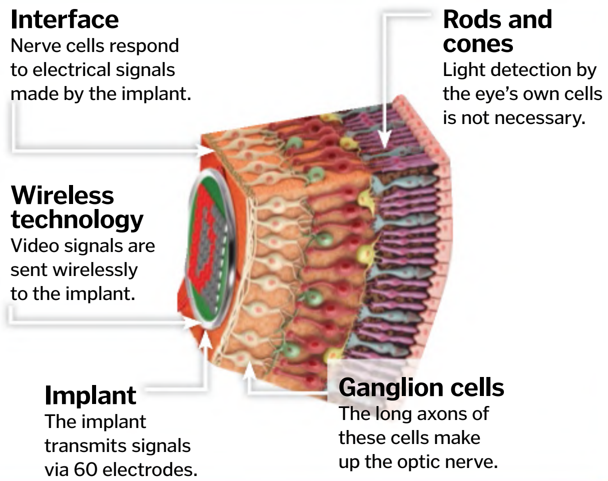
Building a bionic human

Advances in technology make it possible to build limbs with components that mimic the function of the skeleton, musculature, tendons and nerves of the human body. Meanwhile, the sensory system can be replicated with microphones, cameras, pressure sensors and electrodes. Even that most vital organ, the heart, can be replaced with a hydraulic pump. Some of the newest technologies are so advanced that the components actually outperform their biological counterparts.

Retinal implant

Argus II, Second Sight

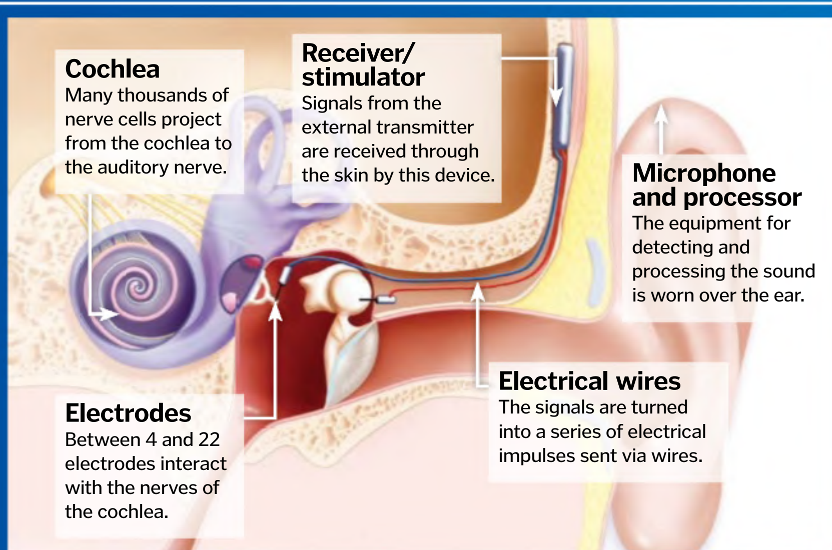
A camera mounted on a pair of glasses captures real-time images and transmits them wirelessly to an implant on the retina. The implant contains 60 electrodes and, depending on the image, will generate different patterns of electrical signals, which are then sent to the remaining healthy retinal cells. These cells are activated by the signals, and carry the visual information to the brain for processing.

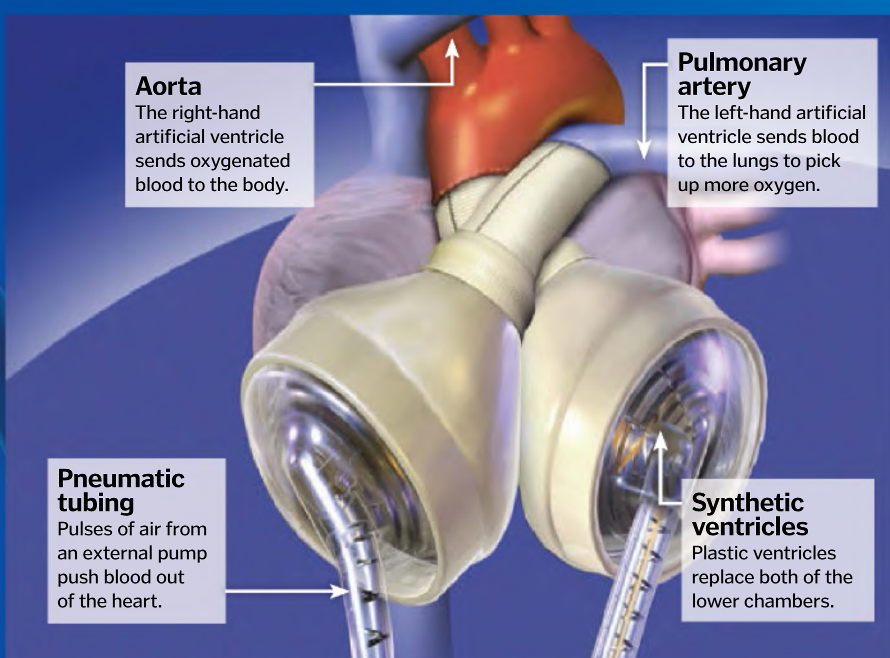


Cochlear implant

Nucleus 6, Cochlear

A cochlear implant has four main components. A microphone, worn near the ear, detects audio and transmits a signal to a sound processor. The processor then arranges the signal and sends it to a built-in transmitter. The transmitter passes the signal to an implanted receiver/stimulator, which transforms it into electrical stimuli for the electrodes. Finally these signals are relayed to the auditory nerve.



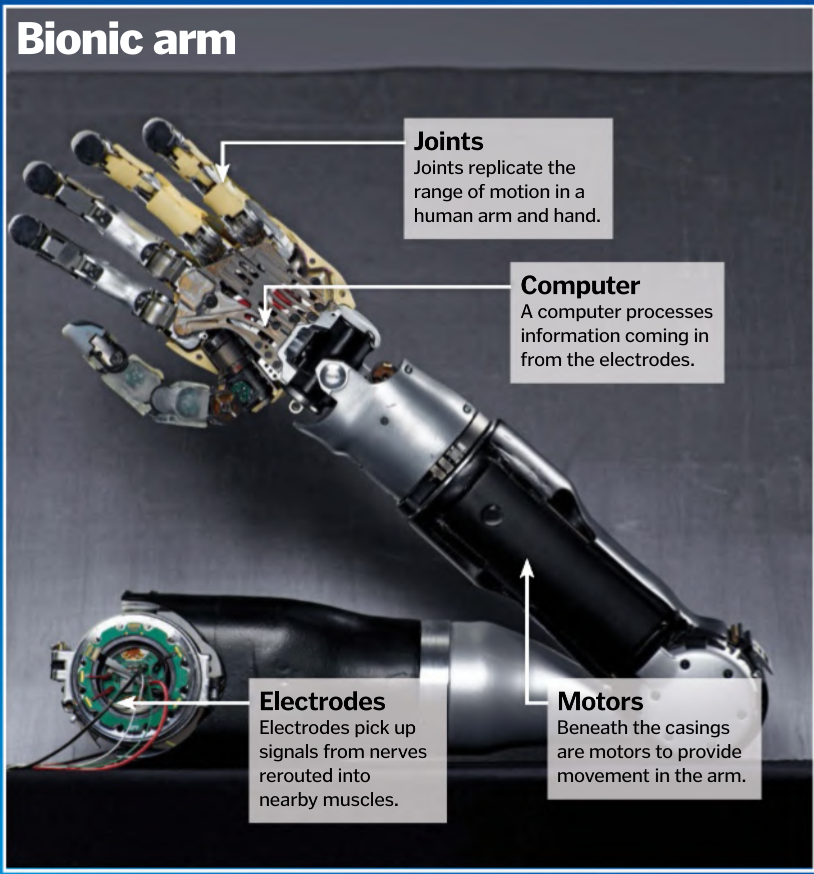


Artificial heart

Total Artificial Heart, SynCardia Systems

Plastic hearts can be implanted to replace the two ventricles of the heart. Plastic tubing is inserted to replace the valves, and two artificial chambers are also attached. The heart is then connected to a pneumatic pump worn in a backpack, which sends bursts of air to the chambers, generating the pressure that's required to pump blood around the body.

Bionic arm



Bionic limbs

Prosthetic limbs have come on leaps and bounds in the past couple of decades. They still retain characteristic features, such as an internal skeleton for structural support and a socket to attach to the amputation site, however the most innovative models are now able to reproduce, or even exceed, biological movements. Motors are used in place of muscles, springs instead of tendons and wires instead of nerves.

The movement of many prosthetics is controlled externally, using cables attached to other parts of the body, or using a series of buttons and switches. New technology is emerging to allow the user to move the limb using their mind (see 'The power of thought'). The next logical step in this process is developing technology that enables the prosthetic limb to sense touch, and relay the information back to the user. DARPA-funded researchers have developed FINE, a flat interface nerve electrode (see below left) which brings nerves into close contact with electrodes, allowing sensory data to pass to the brain.

The future of bionics

1 3D-printed organs
3D printing is the future of manufacturing and biologists are adapting the technology in order to print using living human cells. The cells are laid down in alternating layers alongside a transparent gel-like scaffold material. As the cells fuse, the scaffold disappears.

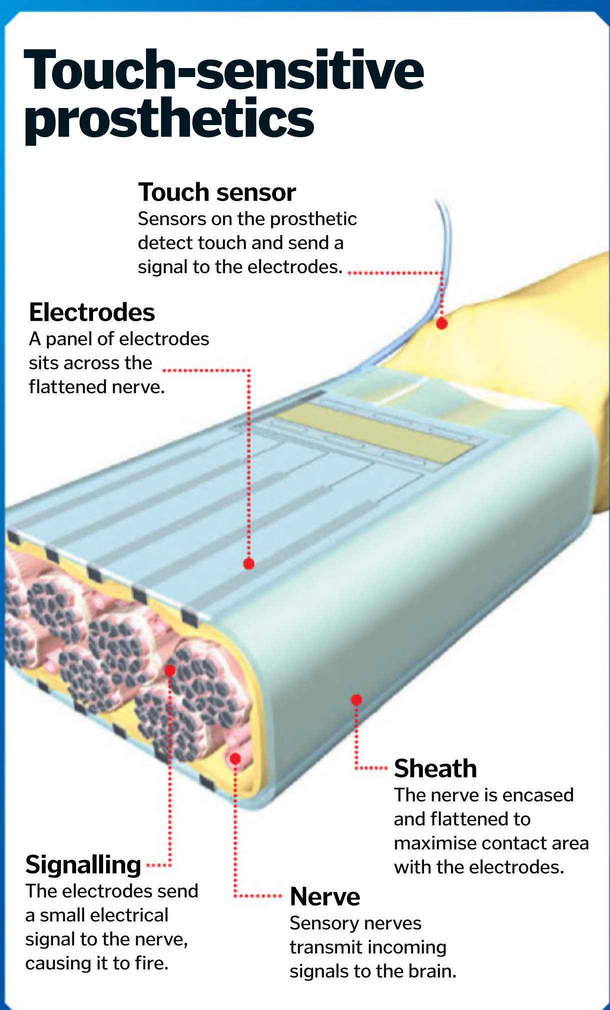
2 Ekso skeleton
Ekso Bionics has made bionic exoskeletons to allow people with lower limb paralysis to walk. Ekso supports their body and uses motion sensors to monitor gestures and then translate them into movement.

3 Artificial kidney
The University of California, San Francisco, is developing a bionic kidney. At about the size of a baseball, it contains silicone screens with nano-drilled holes to filter blood as it passes. It will also contain a population of engineered kidney cells.

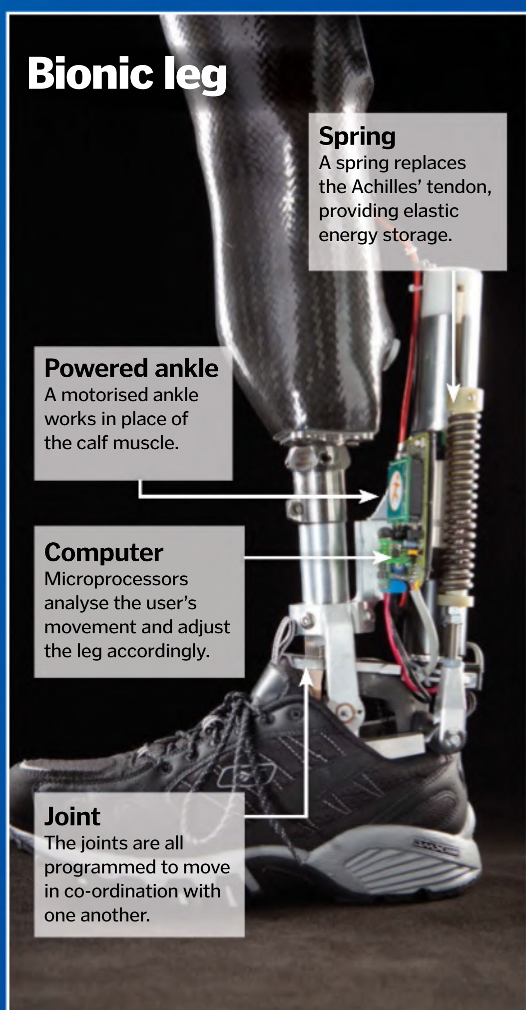
4 Man-made immunity
Leuko-polymersomes are plastic 'smart particles' that mimic cells of the immune system. They are being designed to stick to inflammatory markers in the body and could be used to target drug delivery to infections and cancer.

5 Robotic blood cells
The Institute for Molecular Manufacturing is developing nanotechnology that could increase the oxygen-carrying capacity of blood. Known as respirocytes, the cells are made atom by atom – mostly from carbon.

Touch-sensitive prosthetics



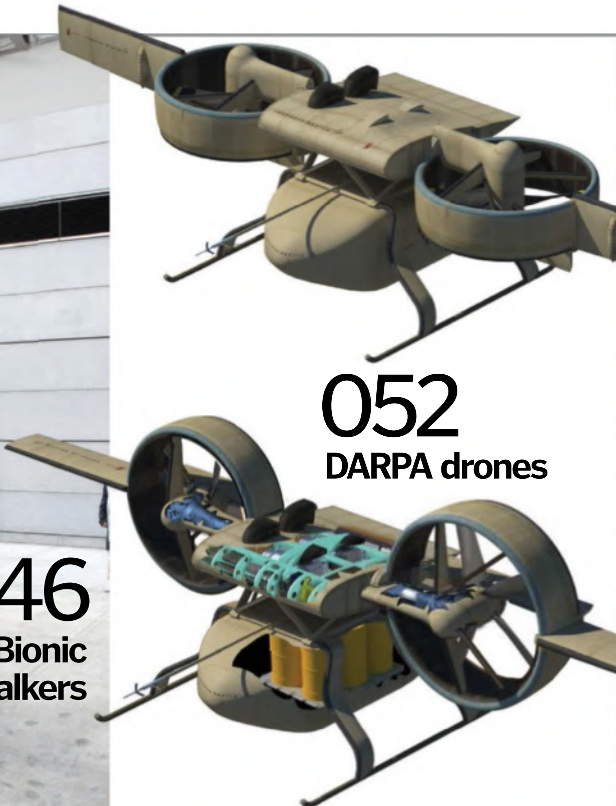
Bionic leg



NEXT-GEN ROBOTS

052
VTOL drone technology

042
Lifesaving tech



ROBOT WARS

Discover the next big thing in sports: giant mechanical monsters that fight to the death

America's MegaBot Mark II

Long-range combat
The Mark II is equipped only with long-range weaponry at the moment, but its planned upgrades include hand-to-hand combat options.

Powerful hydraulics
The robot's legs are fitted with powerful hydraulics, allowing its body to drop down between the treads, making it smaller and easier to transport.

Two-person cockpit
The cockpit fits two people: one sits at the front to control the weaponry and the other sits behind and drives.

Body-mounted cameras
As the driver sits behind the gunner, body-mounted cameras connected to a cockpit monitor are used to help steer the robot.

Pneumatic weaponry
All of the weaponry is powered by high-pressure air, allowing supersized paintballs to be fired at speeds of over 160km/h (100mph).

Tank treads
The robot currently has treads from a Cat 289C Skid Steer loader, but these are likely to be replaced.

Since the birth of science fiction, cinema has been pitting giant robots against each other in colossal fights to the death. The closest we ever got in real life was UK television show *Robot Wars* (and its US counterpart *Battlebots*), where radio-controlled machines went to battle in an area rigged with flame pits, angle grinders and other robot death-traps. Now, we're set to see towering automatons go head-to-head, but these creations won't be judged on damage, control, style and aggression. The winner will be the one left standing.

American startup MegaBots Inc has created their very own piloted, humanoid robot, the MegaBot Mark II. Standing at an impressive 4.6 metres (15 feet) and weighing 5.4 tons, it employs cutting-edge robotics to deliver metal-splitting blows and fire weaponry as the pilots command.

Japan's Kuratas

The Mark II can launch 1.4-kilogram (three-pound) paint-filled cannonballs at a gut-punching 160 kilometres (100 miles) per hour, while its other arm sports a specially designed gun that launches paint rockets. The Megabot's creators explained, "We're Americans, so we've added really big guns." As the juggernauts take chunks out of each other, two brave pilots will be in the cockpit, controlling the Mark II's every move. The driver's view is almost fully obstructed by the robot's gunner, so an intricate camera system has been fitted to relay live video and help the driver see where they are going.

From the beginning of their project, the MegaBots team have had only one thing in mind: epic sports entertainment. Although the Mark II was a first for the US, it was not the first piloted humanoid to be created – a suitable opponent for the MegaBot already existed. Back in the summer of 2012, collaborators from Suidobashi Heavy Industry in Japan unveiled Kuratas, a four-metre (13-foot), single-pilot super-robot.

Despite being older than the Mark II, it's much more impressively equipped, with a superb heads-up display inside the cockpit and more advanced weaponry. One of its signature – if slightly sinister – features is the firing system for its 6,000 round per minute BB Gatling gun. Once the target is locked, the pilot can fire simply by smiling. Trigger-happy has a whole new meaning once you've seen Kuratas in action.

A particularly clever feature of Kuratas is that you don't need to be in the cockpit to operate it. Thanks to the clever V-Sido operating system, you can control the humanoid with any internet-enabled phone, which the designers call the 'Master Slave system'. At the moment this technology only works to control the robot's movement, but could be capable of firing its weapons in the future.

Incredibly, anyone can buy a fully-fledged version of Kuratas right now. It's probably the coolest thing for sale on Amazon Japan, but a fully customisable version will set you back over £650,000 ($990,000). Although the majority of us don't have that kind of cash to splash on humanoid robots, it does go to show that they have arrived, and they're here to stay.

When inventor Kogoro Kuratas received the challenge from the American team, he was quick to accept. Giant robots are a very real part of Japanese culture, and the team are not about to let the Americans defeat them. The duel will take place in June 2016, in a neutral location that's yet to be decided. The two challenge videos have received over 10 million YouTube views between them, so there is definitely enough interest to make this battle truly epic. The sport of the future is here, and it's straight out of science fiction.

The Megabots team have big plans for the Mark II, including increased power and steel armour

Coming soon: Mark II upgrades

With less than a year to go, see how the MegaBots team plan to defeat their Japanese rivals

The designers of the Mark II recognise that they are a number of megabot-sized steps behind Kuratas. To help fund the necessary improvements, they have launched a Kickstarter campaign, in which they detail their plans to create a robot capable of handling anything Kuratas can throw at it. The power unit will be extensively upgraded, giving the Mark II five times its current horsepower, enabling it to cope with the demands of a heavier, energy-sapping frame.

Shock-mounted, steel armour will cover the majority of the Mark II's body, enabling it to withstand considerable punishment from the five-ton-punching Kuratas. The current track base mobility system tops out at a measly four kilometres (2.5 miles) per hour; MegaBots plans to introduce a new, five times faster system designed by Howe and Howe Technology, who have designed similar systems for the vehicles seen in *Mad Max: Fury Road* and *G.I. Joe: Retaliation*.

At the moment the Mark II is very top heavy, and risks toppling over should it take a punch or dish out a particularly powerful one itself. MegaBots is hoping to team up with IHMC Robotics, who specialise in robotic balance and control, making them the ideal company to design a custom system for the Mark II to ensure the robot stays upright no matter what happens.

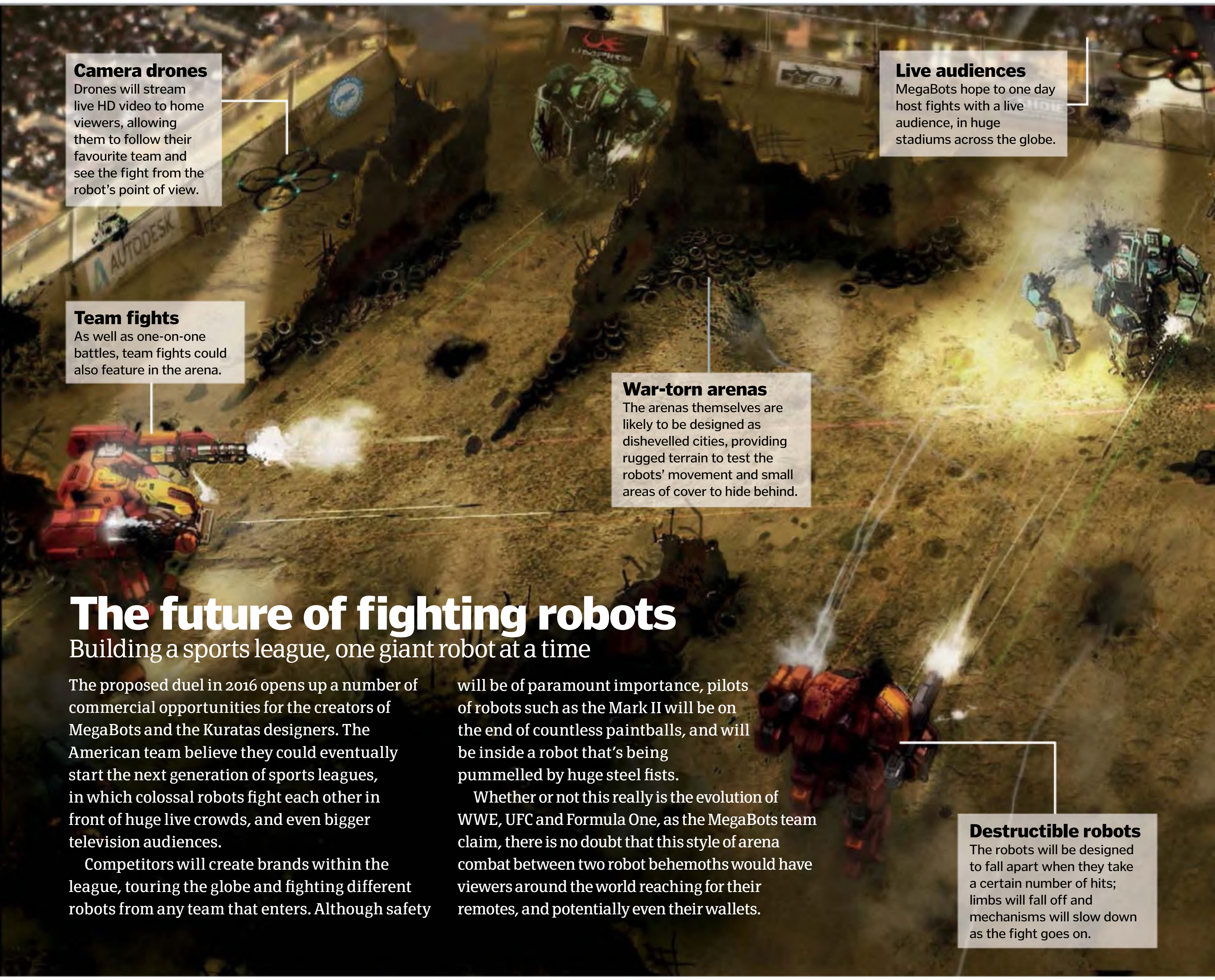
Megabots is planning to include a cigar flamethrower and eagle-mounted Gatling guns

If the Kickstarter campaign raises £800,000 ($1.25 million), MegaBots will seek help from NASA to improve their current cockpit safety system. This will help the robot fight more aggressively without endangering the pilot and gunner inside.

As the creators of Kuratas have demanded that the duel involves hand-to-hand 'melee' style combat, the Mark II will need to be fitted with appropriate weaponry. No one really knows what will work at this scale, but options include crushing and grasping claws, shields and pneumatically-driven fists.

The designers themselves have said they would like to incorporate a giant chainsaw and shoulder-mounted Gatling guns, which fire out of eagle heads. Whichever combination of these gets the go-ahead, watching two giant robots knock the life out of each other will be quite a spectacle.

It is worth mentioning that no details have been released relating to the upgrades that the Kuratas team are planning. The Japanese are keeping their cards close to their chest, but if the current model is anything to go by, they will be mightily impressive.



The future of fighting robots

Building a sports league, one giant robot at a time

The proposed duel in 2016 opens up a number of commercial opportunities for the creators of MegaBots and the Kuratas designers. The American team believe they could eventually start the next generation of sports leagues, in which colossal robots fight each other in front of huge live crowds, and even bigger television audiences.

Competitors will create brands within the league, touring the globe and fighting different robots from any team that enters. Although safety will be of paramount importance, pilots of robots such as the Mark II will be on the end of countless paintballs, and will be inside a robot that's being pummelled by huge steel fists.

Whether or not this really is the evolution of WWE, UFC and Formula One, as the MegaBots team claim, there is no doubt that this style of arena combat between two robot behemoths would have viewers around the world reaching for their remotes, and potentially even their wallets.

The tech behind the robots

Although both the MegaBot Mark II and Kuratas are piloted robots, they both require their own operating system to allow for effective human control. Kuratas uses V-Sido OS, which was designed by the project's head roboticist, Wataru Yoshizaki. In terms of functionality, this software can be compared to the flight control systems, also known as avionics, present in all modern aircraft, as it handles all of the low level tasks while letting the pilot focus on high level commands. Specifically, V-Sido OS integrates routines for balance and movement, helping it to correct posture and prevent the robot from falling over if it is hit during combat or travels over a particularly uneven surface.

The MegaBot Mark II uses Robot OS, an operating system that gives users a flexible framework for writing their own robot software, and is essentially a collection of tools, conventions and libraries that aim to simplify the unenviable task of coding a giant robot. It can be adapted for any mission, making it ideal for MegaBots as they aren't entirely sure how their robot will complete simple undertakings, such as walking and maintaining its balance.

As robotics continue to develop, operating systems will be refined and improved. If robotics advances at the same rate as personal computing has done in the last 20 years, it won't be long before robots are commonplace in both our homes and the workplace.

FUTURE OF ROBOTICS

ROBOTS ARE MAKING GREAT STRIDES – QUITE LITERALLY – SO THE UPCOMING FEW YEARS PROMISE TO USHER IN A WHOLE NEW ERA FOR AUTOMATONS

2x © BAE Systems

Without a doubt, robots have captured the imagination of science-fiction writers and filmmakers over the last 80 years, but even the best efforts of engineers have so far fallen short of this unsettling vision of the graceful, intelligent, self-aware machines that may aim to kill us, love us or become more human.

The application of advanced systems and technology throughout the modern world begs a re-evaluation of the question: what is a robot? Going back to the basic definition of the word, which comes from the Czech *robota*, meaning forced labour, a robot could be anything that performs a physical task for a user.

Available technology has generally limited robot development relative to the imagination of writers and filmmakers. Computer processing capability is currently at a level that allows very sophisticated software to be used, with a large number of advanced sensors and inputs giving huge amounts of information for the software to utilise. One example is the Samsung Navibot, which negotiates its environment with a host of sensors and clever programming to map a room, store the room shape in its memory, define its position and vacuum-clean the floor before returning to a special dock to recharge itself.

Decades of research and development in key areas have begun to pay off, with significant weight reductions and increased structural strength made possible by advancements in carbon fibre and composite material technology. Mechanical and ergonomic research has been instrumental in domestic and care applications, such as the Japanese robot RI-MAN, which easily lifts patients in care homes to save both staff and patients risking injury. Robot/human interaction research is also allowing machines to be tailored to be more widely accepted and trusted, especially with vulnerable or disabled users. NAO is a good

Domestic

ASIMO

Application: Technology demonstrator

Status: Continual development

When it will replace humans: Unknown

Info: The all-new ASIMO is lighter and more streamlined than ever. Its new smaller body belies the awesome tech within though, with ASIMO now capable of improved capabilities (such as talking while delivering drinks) thanks to advanced AI systems and considerably improved movement. ASIMO now has 57 degrees of freedom, can run at 9km/h (5.6mph) and communicate via sign language.

Titanoboa, an exciting project led by Charlie Brinson, is reincarnating a one-ton electromechanical snake

© Michael JP Hall

BAE Pointer

Application: Soldier

Status: In development

When it will replace humans: 2020

Info: BAE's Pointer is a concept vehicle recently presented to the UK government as part of its Future Protected Vehicles programme. The Pointer is a robotic soldier designed to carry out repetitive or dangerous reconnaissance work in the field, eg sweeping for mines. It can travel at high speed on its horizontal tracks or walk like a spider. Its body was designed to be modular, allowing for a variety of configurations, be that a support of human troops with an autocannon, acting as a medibay or delivering battlefield intel as a highly mobile mechanised scout.

ROBOT LAWS

Science-fiction writer Isaac Asimov introduced the three laws of robotics in a 1941 story. These are:

1. A ROBOT MAY NOT INJURE A HUMAN BEING, NOR THROUGH ITS INACTION ALLOW A HUMAN BEING TO COME TO HARM
2. A ROBOT MUST OBEY THE ORDERS GIVEN TO IT BY HUMAN BEINGS, UNLESS SUCH ORDERS WOULD VIOLATE THE FIRST LAW
3. A ROBOT MUST PROTECT ITS OWN EXISTENCE, AS LONG AS THIS DOES NOT CONFLICT WITH THE FIRST TWO LAWS.

Although the Taranis will ultimately be controlled by a team on the ground, it will still be able to make its own judgement calls within a preprogrammed remit

2x © BAE Systems

Military

BAE Taranis

Application: Unmanned combat air vehicle (UCAV)

Status: In development

When it will replace humans: 2018

Info: BAE's Taranis is named after the Celtic god of thunder and has been designed to explore how an autonomous vehicle – controlled by a team of skilled, ground-based operators – can perform many of the roles undertaken by human pilots while remaining non-detectable to radar. Due for flight trials this year, the Taranis relays info back to command at which point it can engage a target if it sees fit.

example of this as its cartoon-like features make it look friendly, which is ideal in its role of supporting the teaching of autistic children.

Integration with other technologies is another key capability of future robotics that is making a huge difference to development, with existing global positioning systems and communication networks allowing autonomy at never-before-seen levels of accuracy, cost and reliability.

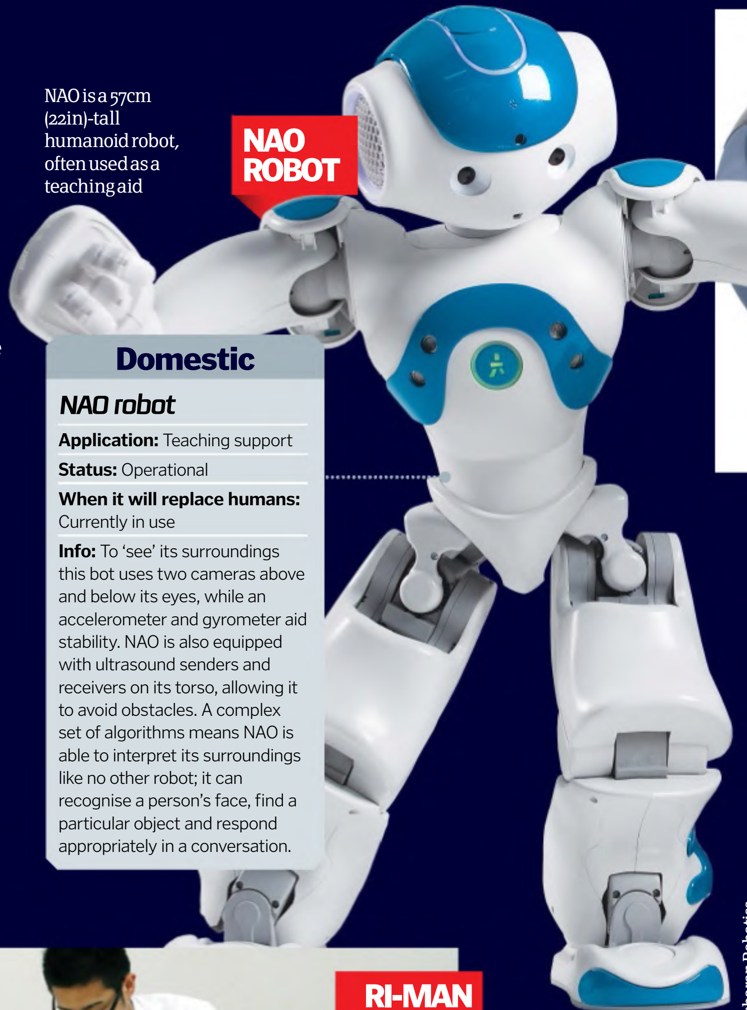
The internet has proven invaluable in offering access to similar lines of research, the sharing of open-source materials and the easy exchange of opinion and resources, which benefits the improvement of technologies. One interesting use of the web is to easily and reliably control robotic systems from anywhere in the world, allowing machines like the da Vinci medical robot to be used by the best surgeons on the planet, while in a different country to the patient if necessary.

Military applications have traditionally pushed the development of all areas of technology, and robotics is an area that is benefiting from this, with many unmanned and autonomous aircraft, tracked and wheeled vehicles, snakes and microbots are being designed to suit modern battlefield situations. Assets such as BAE's Taranis robotic stealth fighter promise high capability, high autonomy and come at a high price, but the development of low-cost, flexible solutions for information gathering, bomb disposal and troop support is evident with the stealthy snake-like robots making excellent progress with several armies, and systems like BAE's Pointer and Boston Dynamics' LS3 taking over many repetitive, dull and risky jobs. We see the benefits of these next-gen robots every day. Autonomous satellites provide GPS navigation for our cars, as well as data links for our mobile phones and computers. Cutting-edge robot technology is making the mass production of items from drinks cans to cars evermore efficient and cost effective, thanks to the progression of industrial robotic systems. Unmanned warehouse and production-line robots move goods around factories, while the level of autonomous control that modern cars have over their brakes, power and stability systems to improve safety takes them very close to the definition of a robot. The mass-market autonomous car is likely only a few years away, with most major manufacturers such as Volvo and BMW having developed driverless technology demonstrators, but it is the human element in this holding the systems back more than the technology, as many people feel very uncomfortable putting their lives in

the 'hands' of a robot driver. Scientific and space research is an area to which next-gen bots are well suited, with machines such as the NASA Dawn spacecraft excelling in their roles. Using an advanced ion engine to move around the solar system, this small, low-budget craft is performing a mission which would be impossible with manned systems. Similar robots can keep humans out of danger in arctic, deep-sea or volcanic research as conducted by the eight-legged Dante II in 1994.

We are on the verge of further technological breakthroughs that will transform the capabilities of robots. The quantum computer may be with us in a few years, and could give a huge increase in processing power while power-generation tech has made a huge leap recently with lithium-based systems. Motors for controlling robots may be replaced with new tech based on expanding/contracting memory metals, electro-reactive materials or other means proving to be more efficient or precise. The next generation of robots is now arriving; who knows what's waiting around the corner?

NAO ROBOT



NAO is a 57cm (22in)-tall humanoid robot, often used as a teaching aid

© Aldebaran Robotics

Domestic

NAO robot

Application: Teaching support

Status: Operational

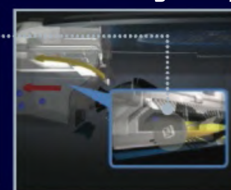
When it will replace humans: Currently in use

Info: To 'see' its surroundings this bot uses two cameras above and below its eyes, while an accelerometer and gyrometer aid stability. NAO is also equipped with ultrasound senders and receivers on its torso, allowing it to avoid obstacles. A complex set of algorithms means NAO is able to interpret its surroundings like no other robot; it can recognise a person's face, find a particular object and respond appropriately in a conversation.

SMART CLEANING

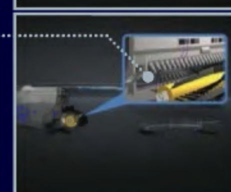
The Samsung Navibot has 38 sensors to map rooms, avoid bumps and recharge itself

1. Looking up The top houses the infrared roof sensor that shows Navibot the shape of the room.

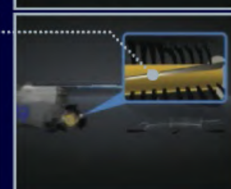


2. Brush Following an efficient pattern within the room, the power brush sweeps the whole floor.

3. Suck-up Dust is sucked up into the bin by the powerful vacuum, from both carpet and smooth floors.



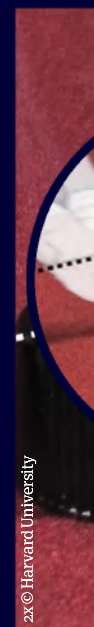
4. Teeth The brush pulls through teeth inside the body, next to infrared sensors which detect drops.



5. Hair-free The anti-tangle system ensures that no long strands of hair jam up the rotating brush.

6. Allergy The hyper-allergenic filter can be cleaned and the vacuum can be set to operate daily.

© Samsung



2x © Harvard University

RI-MAN & RIBA II

RIBA II can lift people weighing up to 80kg (176lb)

2x © Provided by RIKEN-TRI Collaboration Center for Human-Interactive Robot Research

Domestic

RI-MAN and RIBA II

Application: Care work assistance

Status: Operational

When it will replace humans: Currently in use

Info: RIBA (Robot for Interactive Body Assistance) evolved RI-MAN's ability to lift and set down a human; RIBA II can lift up to 80kg (176lb). Joints in the base and lower back allow the bot to crouch down to floor level, while rubber tactile sensors enable it to safely lift a person. These sensors let the robot ascertain a person's weight just by touching them, so it knows how much force to apply when picking them up.

ROBOTIC LANDMARKS

1938
Auto paint sprayer
Harold Roselund and William Pollard pioneer industrial production robotics with an automated paint-spraying arm.

1939
Elektro
While stories depicted intelligent, humanlike robots, this mechanical man appeared at the 1939 World's Fair.

1948
Robot tortoise
With autonomous roaming, obstacle avoidance and light sensitivity, this bot was well ahead of its time.

1950
Isaac Asimov
I, Robot, the book that defined our modern take on robots, was based on Asimov's three laws of robotics.

1954
Programming
The first programmable robot was designed by George Devol, who started Unimation, the first robotics company.

© NASA

Lifesaving

'Soft Robot' Starfish

Application: Search and exploration

Status: In development

When it will replace humans: 2025

Info: Scientists at Harvard University are engineering flexible, soft-bodied (elastomeric polymer) robots inspired by creatures like squid and starfish. Capable of complex movements with very little mechanisation, this sort of bot could be used in search-and-rescue operations following earthquakes. The multi-gait robot is tethered to a bottle of pressurised air, which pulses through the hollow-bodied robot to generate simple motion.

EMILY featured in the top ten of *TIME Magazine*'s 50 best innovations of 2010

2x © Hydronalix

Lifesaving

Emergency Integrated Lifesaving Lanyard (EMILY)

Application: Lifeguard

Status: Operational

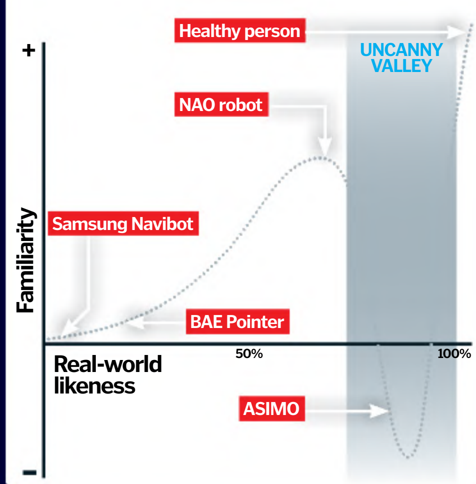
When it will replace humans: Currently in use

Info: EMILY is a 1.5m (5ft)-long remotely controlled buoy used to rescue swimmers in distress. The buoy can race across the ocean at 39km/h (24mph), enabling swift rescues. It has been advanced with sonar-detection tech which helps it to find and identify distressed swimmers on its own. Once EMILY has reached the swimmer, they can either hang on to the buoy and await a lifeguard, or the buoy can tow them ashore itself.

These soft-bodied robot sea-creatures, whose development is supported by DARPA, could one day be saving lives

UNCANNY VALLEY

Humans have evolved to be repelled by certain things. Aversions to smells, tastes and the way things look are ways of protecting ourselves, eg a dead body produces a strong feeling of discomfort, even if it's much the same as a living one. The 'uncanny valley' theory states we show greater affection towards objects as they become more humanlike, but there comes a point where they get too close, in manner or appearance, triggering repulsion. The key is for robots to be endearing but not too realistic.



Exploration

Festo SmartBird

Application: Technology demonstrator

Status: Operational

When it will replace humans: Currently in use

Info: This robot is about the size of a condor and, using an array of internal sensors, is able to fly autonomously. It is incredibly light, (450g/2.8oz), despite having a wingspan of 2m (6.4ft). The wings, which move up and down thanks to a host of gears, are similar to a jumbo jet's – thick at the front and thinner at the back with rods providing support; they can also twist to alter the direction of the robo-bird.

© SmartBird, Festo

> "Traditional motors for controlling robots may be replaced with tech based on expanding/contracting memory metal"

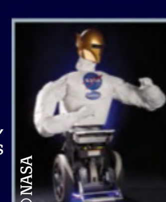
1957 Sputnik I
The very first space robot, though primitive by modern standards, kicked off the Space Race.

1970 Computer control
The Stanford Research Institute develops the first robots that are controlled by computers; these were called Cart and Shakey.

1986 Honda EO
Honda begins building walking humanoid robots, investing 25 years and huge resources into development; this leads on to ASIMO.

1997 RoboCup
The first tournament that aims to have a robot football team one day beating humans is held.

2011 Robonaut 2
NASA launches the second robot astronaut, which can operate tools and assist human astronauts in orbit.



© NASA

2020? Next-gen robots
The next few years should see robots with quantum computer brains and biomechanical muscles become a reality.

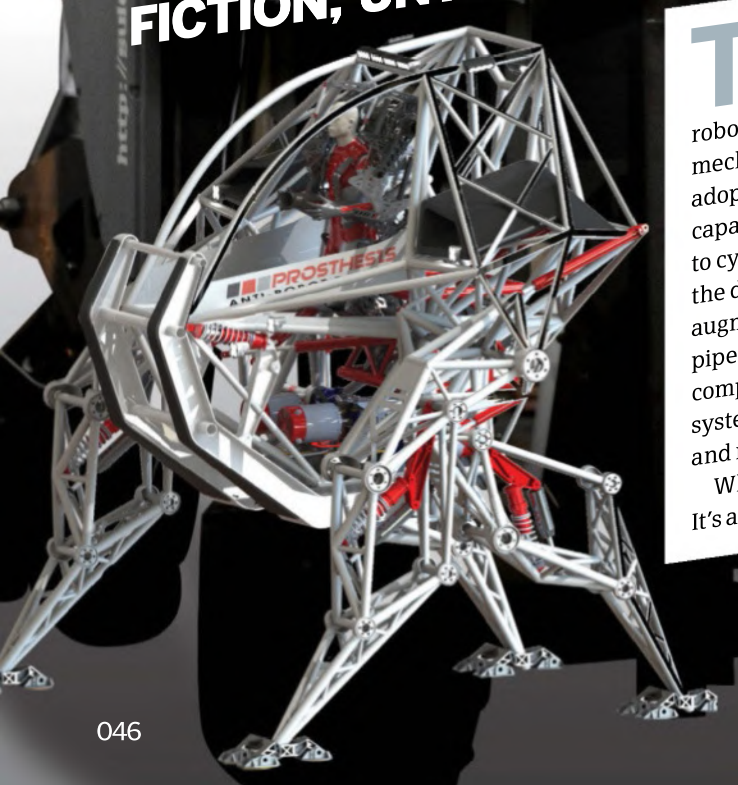
EXO SUITS

THE FUSION OF MAN AND MACHINE WAS THOUGHT THE STUFF OF SCIENCE FICTION, UNTIL NOW

The *Iron Man* suit is no longer the sole domain of comic books and film superheroics. Thanks to advanced robotics and human-machine interfaces, mechanised exoskeletons are being adopted worldwide. From machines capable of turning men into super-soldiers to cyborg implants clever enough to make the disabled mobile, the concept of human augmentation is rapidly transitioning from pipe dream to power on, with a host of companies and developers producing systems to make humans quicker, stronger and more perceptive.

Why is this revolution happening now? It's a combination of advanced discussion regarding the ethics of such augmentations by the Earth's brightest minds and a ravenous, insatiable drive by science and technology corporations to take humanity into a glorious new age. Before, scientific developments such as these would have been stamped out by fanatics, now if a person is born without the use of their legs they will still be able to walk and live their life like they never thought possible.

Strap yourself in and power up your mind as we take you on a tour through some of the most groundbreaking advancements changing the world in the fields of robotics and bionics. Welcome to the human-machine fusion revolution.



HAL

HUMAN LIMBS EVOLVED

One of the most useful developments in human augmentation right now is Cyberdyne Inc's Hybrid Assistive Limb, codenamed HAL. HAL is the world's first cyborg-type robotic system for supporting and enhancing a person's legs, giving them the ability to walk if disabled.

Attached to the user's lower back and legs, HAL works in a five-step process. The user merely thinks about the motions they want to undertake, such as walking. This causes the user's brain to transmit nerve signals to the muscles necessary for the motion to take place. At this stage, a disabled user wouldn't be able to receive these nerve signals correctly in their limb muscles, but with HAL attached, they can. HAL is able to read the user's emitted bio-electric signals (BES), faint subsidiary signals from the brain-muscle signals that extend to the surface of the user's skin. By detecting these signals, HAL is then able to interpret the motion intended by the user and execute it, allowing them to move.

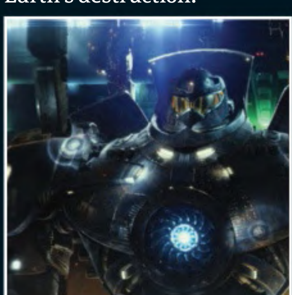
What is most exciting about HAL is its potential to train disabled individuals to move without its help. That is because every time HAL helps its user move, a natural feedback mechanism sees the user's brain confirm the executed movement, training the user's body to transmit those nerve signals correctly. While still some way off, continued development could eventually see HAL train a disabled person to walk unassisted.

Top 5 movie mechs

Gipsy Danger

Pacific Rim (2013)

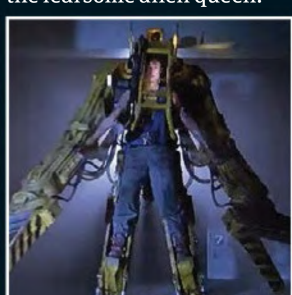
One of the most important mechs from 2013's *Pacific Rim*, Gipsy Danger helps humanity combat inter-dimensional beasts bent on Earth's destruction.



Power Loader

Aliens (1986)

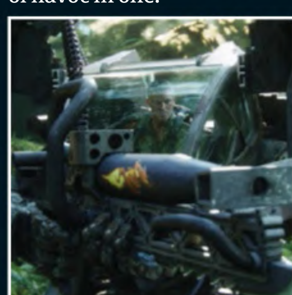
Piloted by Ripley in James Cameron's *Aliens*, the Power Loader mech helps Sigourney Weaver's feisty protagonist face off against the fearsome alien queen.



AMP

Avatar (2009)

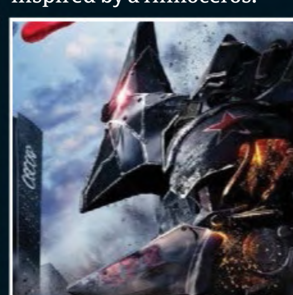
Another hot mech from the mind of James Cameron, *Avatar*'s AMP plays a key role in the film's finale, with the baddie wreaking a whole lot of havoc in one.



Rhino

The Amazing Spider-Man 2 (2014)

Russian mobster Aleksei Sytsevich breaks out of prison and tears up Manhattan in a mech suit inspired by a rhinoceros.



APU

The Matrix Revolutions (2003)

Protecting the remnants of humanity against the sentinels of the *Matrix* universe, the APU deals huge damage with big guns.

No longer the sole domain of comics and movies like *GI Joe*, exoskeletons are helping soldiers in the field

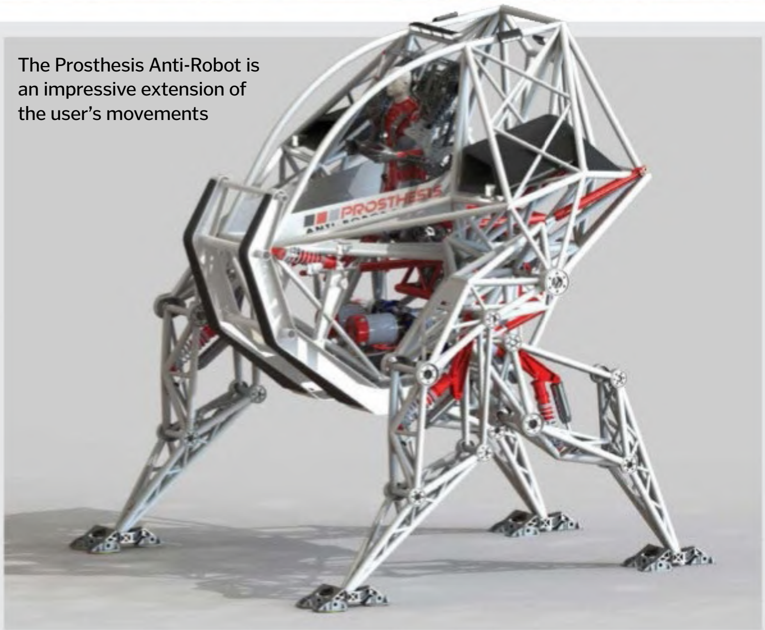
HULC

FASTER, STRONGER, TOUGHER

While Cyberdyne Inc's HAL is helping disabled people move once again, Lockheed Martin's HULC Exoskeleton is transforming able-bodied soldiers into mechanised warriors capable of feats of strength, speed and endurance never before seen by humans.

A hydraulic exoskeleton, the HULC allows soldiers to perform superhuman feats such as carrying loads of 90 kilograms (200 pounds) over difficult terrain for hours on end, all the while retaining maximum mobility. It achieves this by augmenting the soldier with a pair of powered titanium legs and a computer-controlled exoskeleton with a built-in power supply. This mechanism transfers the weight carried by the soldier into the ground, while providing power for continued, agile movement in the theatre of war.

Due to the HULC's advanced composite construction and build materials, it also acts as armour for its user, protecting them from musculoskeletal injuries caused by stress from carrying heavy loads. Indeed, when you consider that HULC may also improve metabolic efficiency in its user, reduce oxygen consumption and improve the rate of muscle wear, its hard not to see the future of frontline combat becoming reliant on these mech warriors.



The Prosthesis Anti-Robot is an impressive extension of the user's movements

RACING BOT

THE ULTIMATE PROSTHESIS

The Prosthesis Anti-Robot is a towering machine operated purely by human body movements. If that doesn't impress you, how do you feel knowing the Anti-Robot weighs over 3,400 kilograms (7,500 pounds) and is 4.6 metres (15 feet) tall?

The pilot can move such a huge machine by their own efforts thanks to an interface that attaches to their arms and legs and translates the movements of their limbs into the robot's four hydraulic legs. This, along with positional and force feedback, means the pilot's limbs directly correlate to those of the machine and when the force on them increases, the limbs get harder to move. A suspension system also helps the pilot feel when the bot's feet connect with the ground.

The Anti-Robot clearly highlights the possibilities of exoskeletons, with human strength and speed not only dramatically increased but also transferred into a machine many times their size. It's not hard to foresee construction workers suited up and shifting huge crates with ease in the near future.

The rise of the mechs

A timeline of real-life robotic tech

1961
Jered Industries in Detroit creates the Beetle, a tracked mech tank weighing 77 tons. The pilot is shielded by steel plating.

1968
General Electric creates the first cybernetic walking machine, a piloted mech with hydraulic hands and feet.

1989
MIT creates Ghengis, a small robot insect capable of scrambling over rough terrain while remaining stable.

1993
Honda unveils its first humanoid robot, the P1, which can walk around on two feet while tethered. It evolves into the now-famous ASIMO.

2000
DARPA, the US Defense Advanced Research Projects Agency, requests proposals for a powered military exoskeleton. It chooses the Sarcos XOS.

BIONIC WALKER

SUIT UP!

The most advanced gait-training exoskeleton currently in use, the Ekso Bionic Suit has been specially designed to grant people with paralysis a means of standing and walking. Once wearing the Bionic Suit, those who have suffered from neurological conditions such as strokes, spinal cord damage or traumatic brain injury can re-learn correct step patterns and weight shifts – things that able-bodied humans take for granted – all the while supported by a system that assists when needed and records every movement for later analysis.

The Bionic Suit already has an shining record, with every medically cleared user walking in the suit in their first training session. Fitting the suit takes just five minutes so doctors can treat multiple patients, with the suit simply affixed over a user's normal clothes. Considering that it also offers multiple training modes, progressing its wearer from being unable to walk right through to various motor levels, and that Ekso has only been in operation since 2005, it's easy to see how the technology could transform lives.

Walking modes

First steps

A physical therapist controls the user's steps with button pushes, with the wearer supporting themselves with crutches.

Active steps

In the second stage, the user takes control of their limb movements through button pushes on a set of smart crutches.

Pro steps

In the most advanced stage, the exoskeleton moves the user's hips forward, shifting them laterally into the correct walking position.

Anatomy of the Ekso Bionic Suit

Check out the core components and features of this revolutionary exoskeleton

Power plant

The Bionic Suit is powered by a brace of high-capacity lithium batteries that can energise the exoskeleton for up to four hours.

Computer

A central computer system receives data from the Bionic Suit's 15 sensors to fine-control the user's leg movements.

Motors

Four electro-mechanical motors drive movement at the user's hips and at each knee.

Crutches

If needed, a set of smart crutches can be used by the user to control their leg movements with arm gestures.

Fixed assist

Each of the exoskeleton's legs is fitted with a fixed assist system that can contribute a fixed amount of power to help the user complete a step.

Joints

The exoskeleton's mechanised joints are designed to allow the user to bend their limbs as naturally as possible.

Pegs

Heel pegs help secure the wearer's feet and ensure they don't stumble while training on uneven ground.

Adaptive assist

Depending on the strength and capability of the user, the Bionic Suit can be adjusted to produce various smooth and natural gaits.

2004

TMSUK and Kyoto University reveal the T-52 Enryu, one of the first rescue robots to be used by Japanese emergency services.

2006

Japanese machinery and robotics manufacturer Sakakibara-Kikai produces the first genuine bi-pedal mech. The machine measures a huge 3.4m (11.2ft) tall.

2009

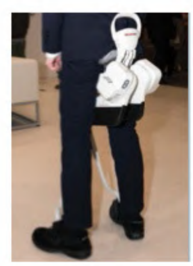
Lockheed Martin reveals its Human Universal Load Carrier (HULC), an exoskeleton purpose-built to be worn by US soldiers.

2011

Rex Bionics launches the Rex exoskeleton, a device that consists of a pair of robotic legs that can help people with paraplegia to stand and walk.

2013

Honda begins US trials of its Walking Assist Device at the Rehabilitation Institute of Chicago. The product aims to help stroke patients walk again.

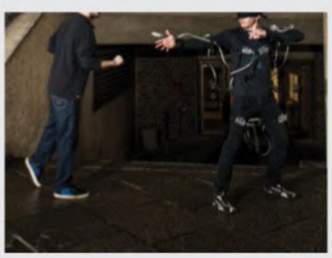


Real-life spidey sense

Ever thought it would be cool to have the 'spidey sense' of *Spider-Man* in real life? Well, now you can, thanks to a neat research project undertaken by the University of Illinois. SpiderSense is a wearable device that, by manipulating the some of the millions of sensory receptors located on human skin, can relay information about the wearer's environment to them. This clever tech means that despite being blindfolded, the user would know exactly where they were in relation to moving objects.

The system works thanks to the SpiderSense's wearable tactile display, which consists of a series of sensor modules affixed to the user's arms and legs. As the user moves about a room, distance information regarding its objects are relayed to the user through the pads via increases or decreases in pressure, with the skin's receptors relaying that information to the brain. The sensor modules scan the environment using ultrasound, repeatedly sweeping an environment for objects and barriers in the way.

In terms of applications, technology like SpiderSense could be used to compensate for a dysfunctional or missing sense, such as visual impairment, or to augment someone's fully functional senses.

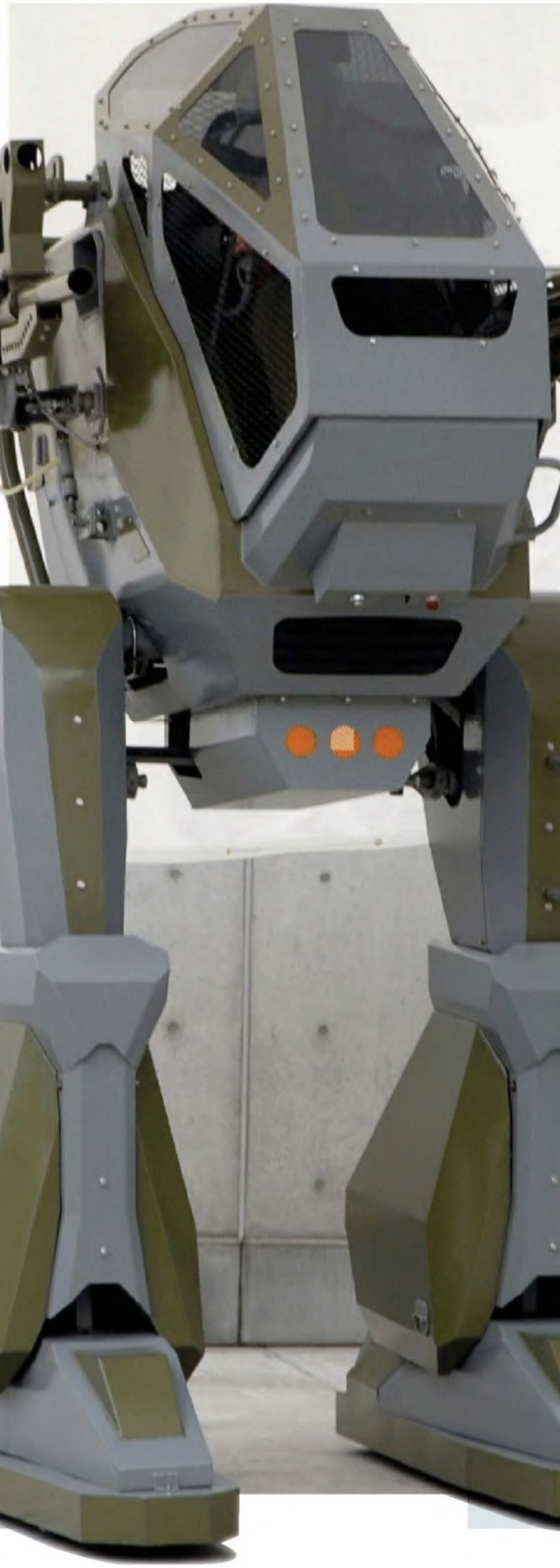


LAND WALKER

BATTLEMECH POWER

On the most extreme side of the mech revolution sits Sakakibara-Kikai's Land Walker, a 3.4-metre (11.2-foot) tall, 1,000-kilogram (2,200-pound) bipedal exoskeleton. Designed to replicate the battle mechs of popular science fiction, such as the AT-STs of the *Star Wars* films, the Land Walker is the world's first machine of its kind, capable of moving around on two feet, thunderously plodding around under the command of its human pilot. The Land Walker is powered by a 250cc four-stroke engine, can walk around at 1.5 kilometres (0.93 miles) per hour and is equipped with an auto-cannon capable of firing squishy rubber balls. Unfortunately, the Land Walker currently retails for £210,000 ($345,000), so it might be some time before you can stomp to work in one.

While the Land Walker's current performance arguably leaves a lot to be desired, with more development funding, a machine such as this could easily become the future of law enforcement, with its intimidating physical presence and – if armed correctly – damage-dealing capabilities more than a match for any civilian vehicle.



The Land Walker is still a novelty device but has great future potential

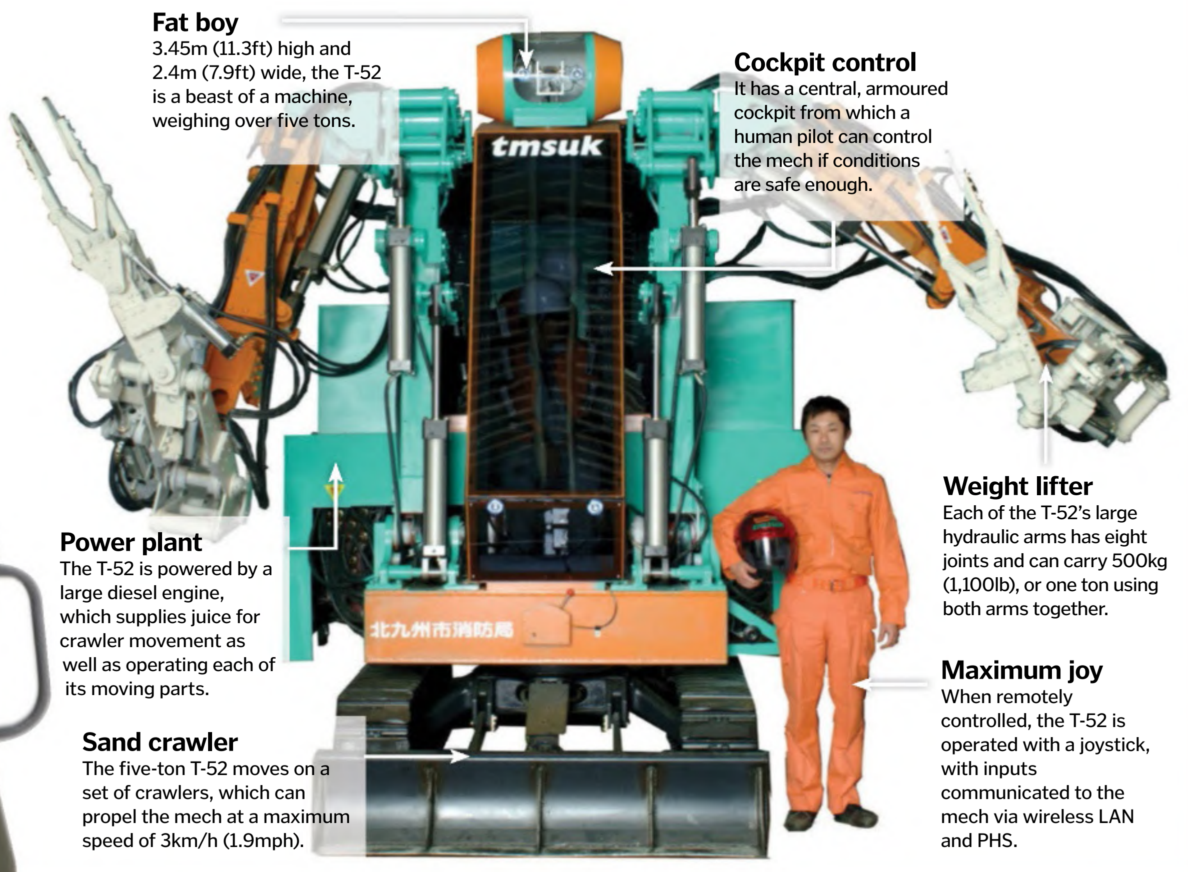
ENRYU

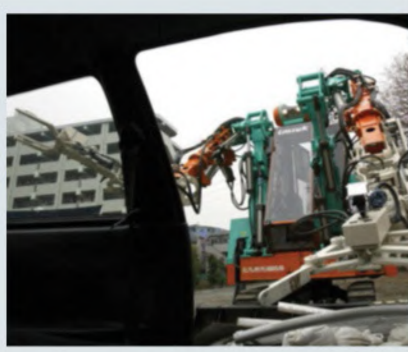
ROBOTIC RESCUE DRAGON

A large-scale, human-controlled robot for use in disaster sites, the T-52 Enryu (which translates as 'T-52 Rescue Dragon') is one heck of a piece of kit. At 3.45 metres (11.3 feet) tall and 2.4 metres (7.9 feet) wide, it's packed with seven 6.8-megapixel CCD cameras and the ability to lift objects weighing up to one ton with its hydraulic arms. The T-52 is arguably the most advanced disaster-relief mech in service, infiltrating hazardous areas and withstanding conditions a human never could.

The mech was built by the Japanese company TMSUK in partnership with Kyoto University and Japan's National Research Institute of Fire and Disaster for undertaking heavy-duty work in disaster areas. The T-52 can either be operated from its armoured cockpit or remotely from a control station, with the pilot receiving contextual information via a series of LCD displays.

The machine specialises in lifting large and heavy objects, meaning that it can easily help free people trapped in earthquake-generated building collapses. While the Rescue Dragon is still in its development phase, it has already passed a number of operational tests and was recently deployed to help clear up the Fukushima Daiichi nuclear plant disaster of 2011, patrolling the site and removing large pieces of radioactive rubble.





The best of the rest

1 Kuratas

The ultimate executive toy, the Kuratas mech allows its owner to ride around in its futuristic cockpit while firing 6,000 BB rounds per minute from its dual, arm-mounted Gatling guns.

2 Cybernetic Anthropomorphous Machine

One of the first mechs ever built, the CAM was designed and built for the US Army in 1966 to move cargo and weapons across battlefields.

3 Sarcos XOS 2

An exoskeleton that grants its wearer superhuman strength, the XOS 2 is currently being trialled by the US Army, with a finished untethered variant set to enter service in 2020.

4 Body Weight Support Assist

Honda's Body Weight Support Assist from is a partial exoskeleton that, once worn, helps to support the user's upper body, taking some of its weight off their legs.

5 Raytheon Heavy Lifter

Designed to move large crates, containers and objects, the Heavy Lifter offers its user a high degree of freedom and agility.

6 Kid's Walker

The Land Walker's baby brother, the Kid's Walker – which costs about £12,000 ($20,000) – is designed to allow children to pilot their own toy mech while remaining safe.

VTOL drones

From the humble helicopters of yesterday, to the robotic drones of tomorrow: vertical lift technology is on the rise

Almost as far back as humans have been dreaming of inventions for flight, they have been envisioning craft capable of vertical takeoff and landing (VTOL). Leonardo da Vinci is responsible for some of the earliest designs for today's most common VTOL aircraft – the helicopter. It may have only been an untested imagining of a flying machine that never got off the ground, but this so-called 'aerial screw' harnessed the essential principles of lift through air compression – utilising a corkscrew design.

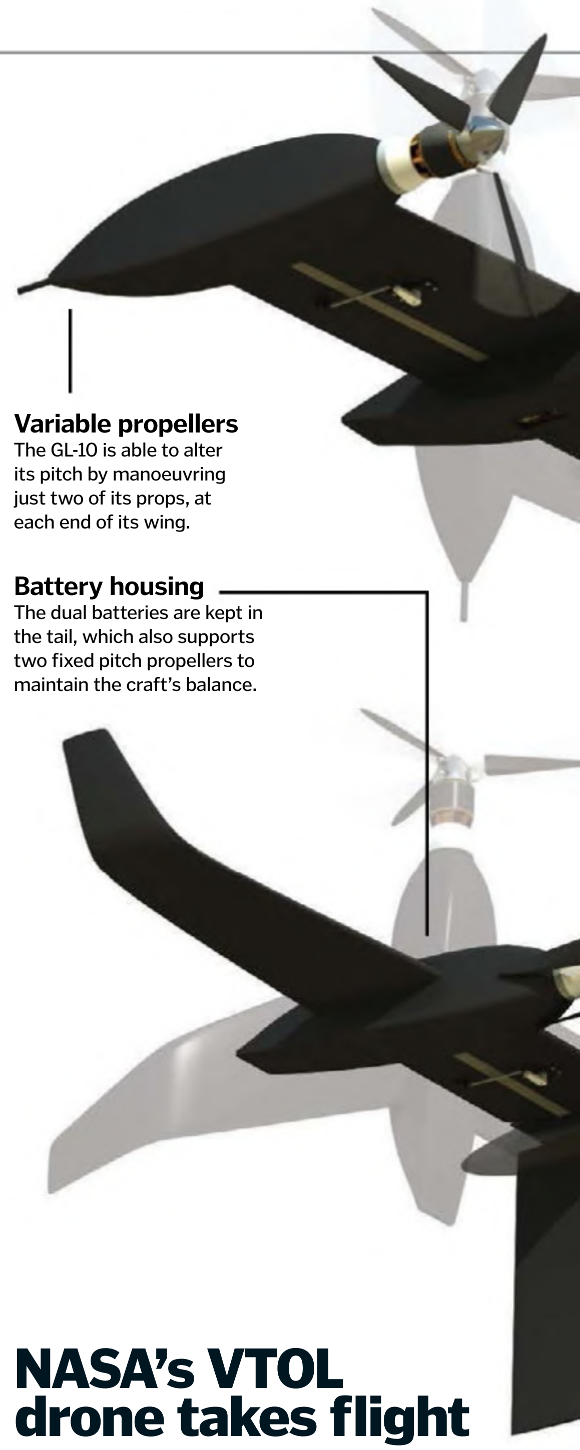
Though scores of inventors and pioneers attempted to take to the skies in their own prototypes, over the following five hundred years not much further progress in VTOL flight was made. However, though the gyrocopter design was left well behind, the Italian genius's principles of flight in essence remained much the same.

The beginning of the 20th century saw the age of flight dawn, and by 1907 some of the first-ever successful VTOL tests took place in France. Aviation pioneers Jacques and Louis Breguet, as well as Paul Cornu, had developed VTOL craft capable of hovering some feet off the ground for a short length of time – the first baby steps of vertical flight.

The following decades saw aviation technology race skyward, with designs popping up all over the globe. Though the Great War saw a huge demand for newer, faster and more-efficient aircraft to fight the enemy, helicopter designs were largely ignored until the 1940s and the Second World War. Nazi Germany used some early helicopters for reconnaissance, transportation and medical evacuation, but it wasn't until 1944 that the first mass-produced helicopter was revealed.

Hundreds of engineer Igor Sikorsky's R-4, R-5 and R-6 helicopter models were built during the final year of WWII to aid the Allies, and by the end of the war the VTOL craft was quickly gaining acclaim. Unlike da Vinci's gyrocopter design, this modern helicopter used rotor-blades to rapidly compress air downwards to create the necessary lift, and a tail rotor-blade to prevent the aircraft spinning.

As the world cooled into the threatening Cold War, it was the opinion of many that VTOL craft ▶



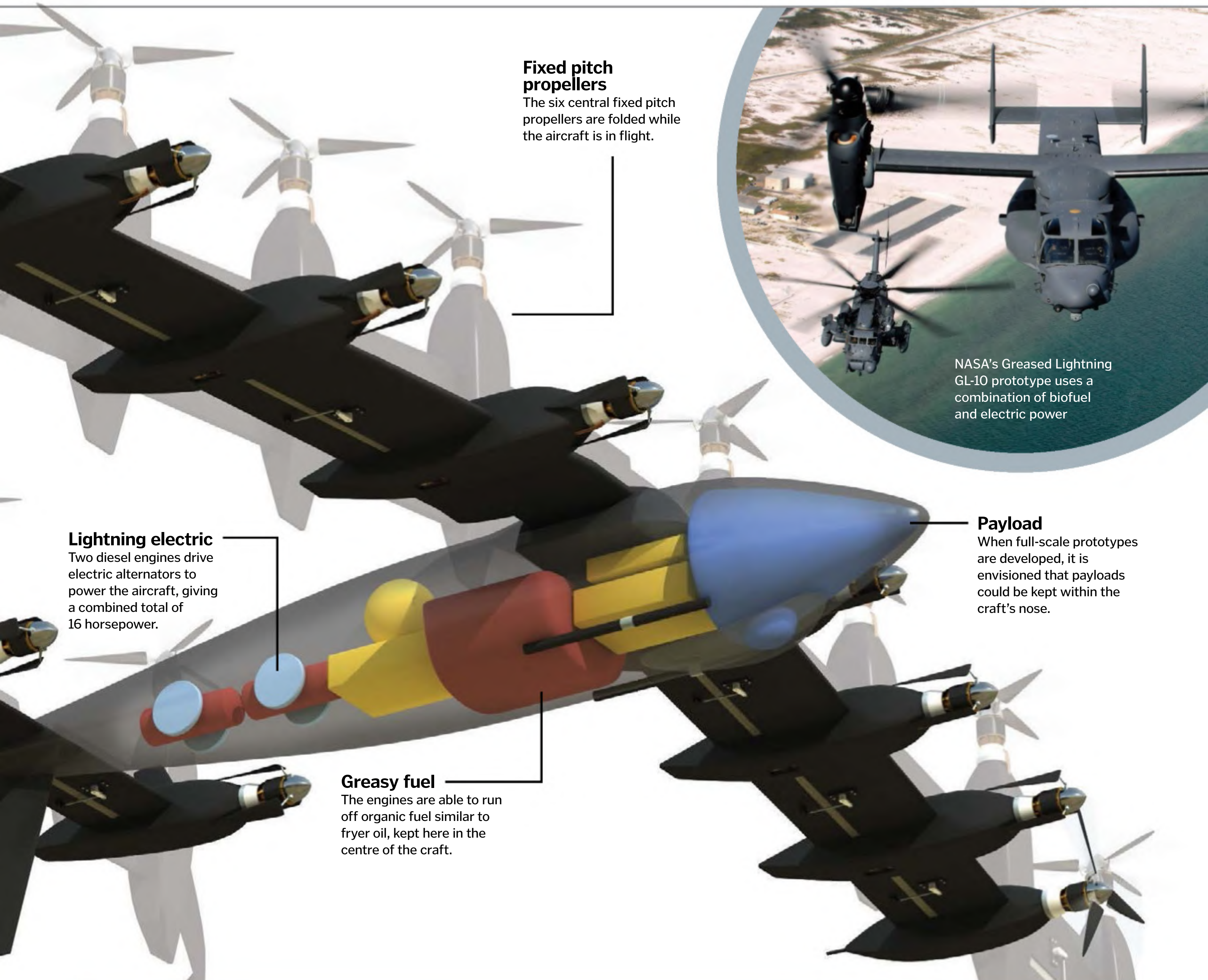

The GL-10 on its maiden test flight in 2014, tethered by a safety cable

NASA's VTOL drone takes flight

NASA's hybrid-electric craft, dubbed Greased Lightning GL-10, may only have a three-metre (ten-foot) wingspan, but it has already shown promise for stretching VTOL technology much further. Its ten distinctive propellers provide maximum lift efficiency while travelling vertically, before both wing and tail panels tilt to transfer GL-10 to horizontal flight. Only two propellers do all the work at this point, to save energy, while the rest fold back aerodynamically.

It's the combination of biofuel and electric power that gives the craft its nickname – the grease of the fuel and the lightning of the batteries. The hybrid design of the engine means it's far less cumbersome than a standard jet or combustion engine, enabling not only a sleeker design but also far less wasted energy.

While the GL-10 prototype is obviously far too small for transporting any significant payload, NASA has revealed its GL-10 represents a 'scale-free' design, meaning the weights and measures of Greased Lightning could work in much larger sizes. This means that craft similar to GL-10 may become more and more common if further tests are successful.



NASA's Greased Lightning GL-10 prototype uses a combination of biofuel and electric power

The most famous VTOL aircraft

V-22 Osprey
Developed by US manufacturers Bell and Boeing, the Osprey's two unique tilt-rotor propellers provide its VTOL ability. They also enable the craft to reach speeds of up to 500km/h (311mph).

BAE Sea Harrier
Developed during the 1970s, the Harrier Jump Jet utilises four separate vector nozzles to direct its engine thrust. In this way it is able to transition from vertical to horizontal flight, and even hover.

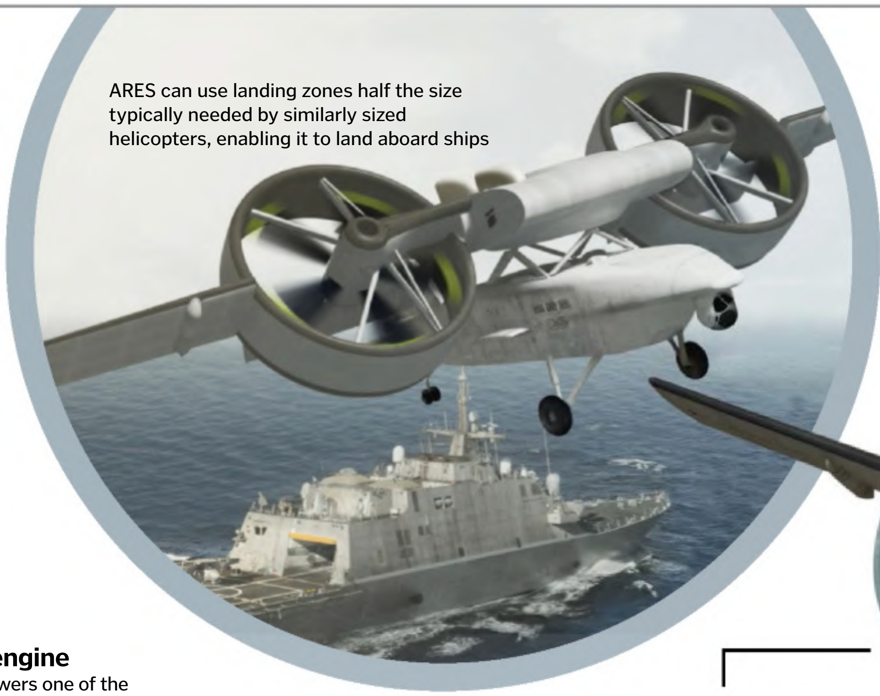
Boeing CH-47 Chinook
Considered one of the great workhorses of modern militaries all over the globe, the Chinook's twin-rotor design enables it to transport hefty payloads of up to 10,886 kilograms (24,000 pounds).

Unmanned VTOL goes to war

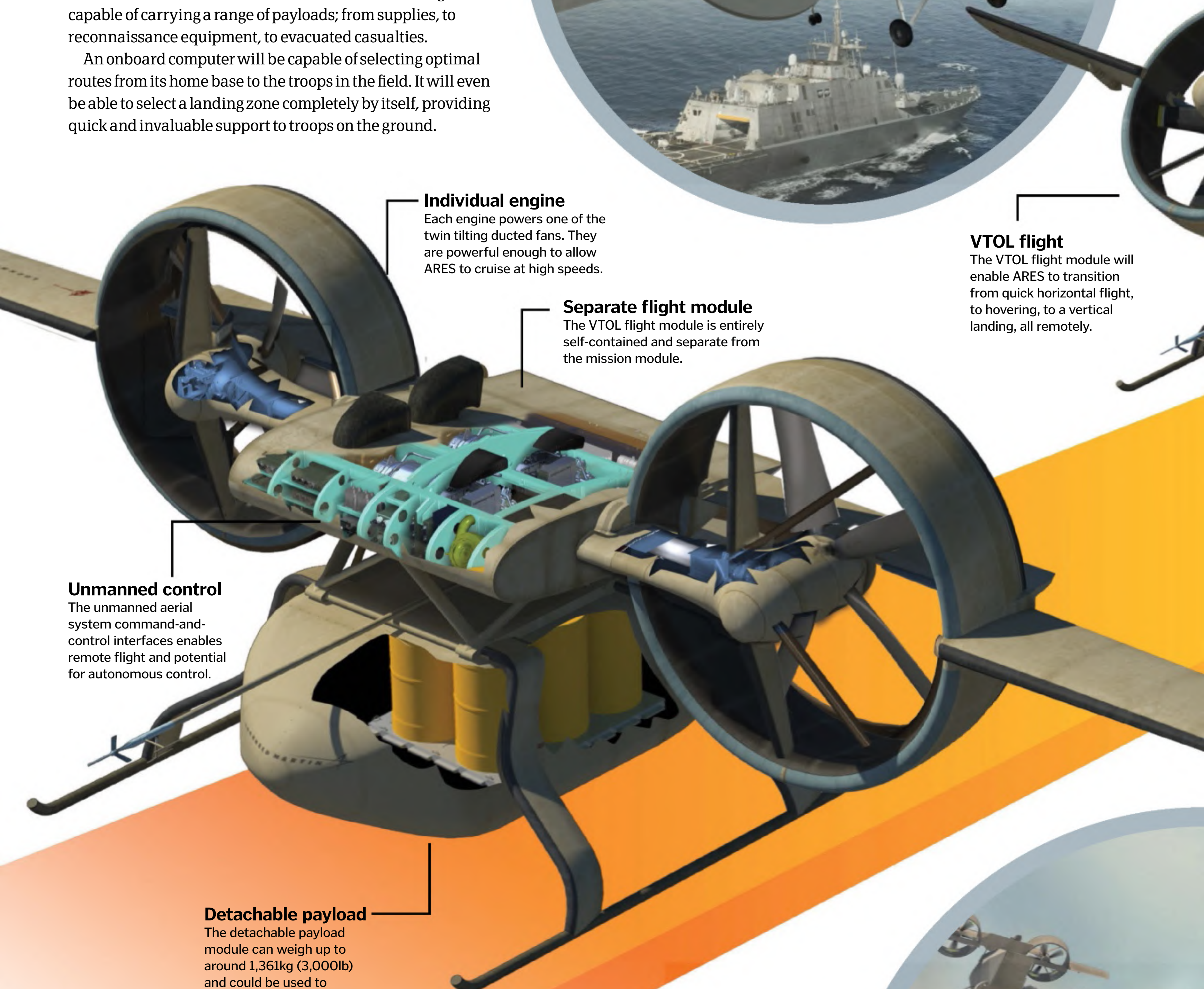
How DARPA's Aerial Reconfigurable Embedded System (ARES) could change the face of frontline combat

In a bid to overcome the problem of transporting supplies across difficult and often dangerous battlefield terrains, DARPA has turned to unmanned VTOL drones. The ARES design is capable of carrying a range of payloads; from supplies, to reconnaissance equipment, to evacuated casualties.

An onboard computer will be capable of selecting optimal routes from its home base to the troops in the field. It will even be able to select a landing zone completely by itself, providing quick and invaluable support to troops on the ground.



ARES can use landing zones half the size typically needed by similarly sized helicopters, enabling it to land aboard ships



Individual engine
Each engine powers one of the twin tilting ducted fans. They are powerful enough to allow ARES to cruise at high speeds.

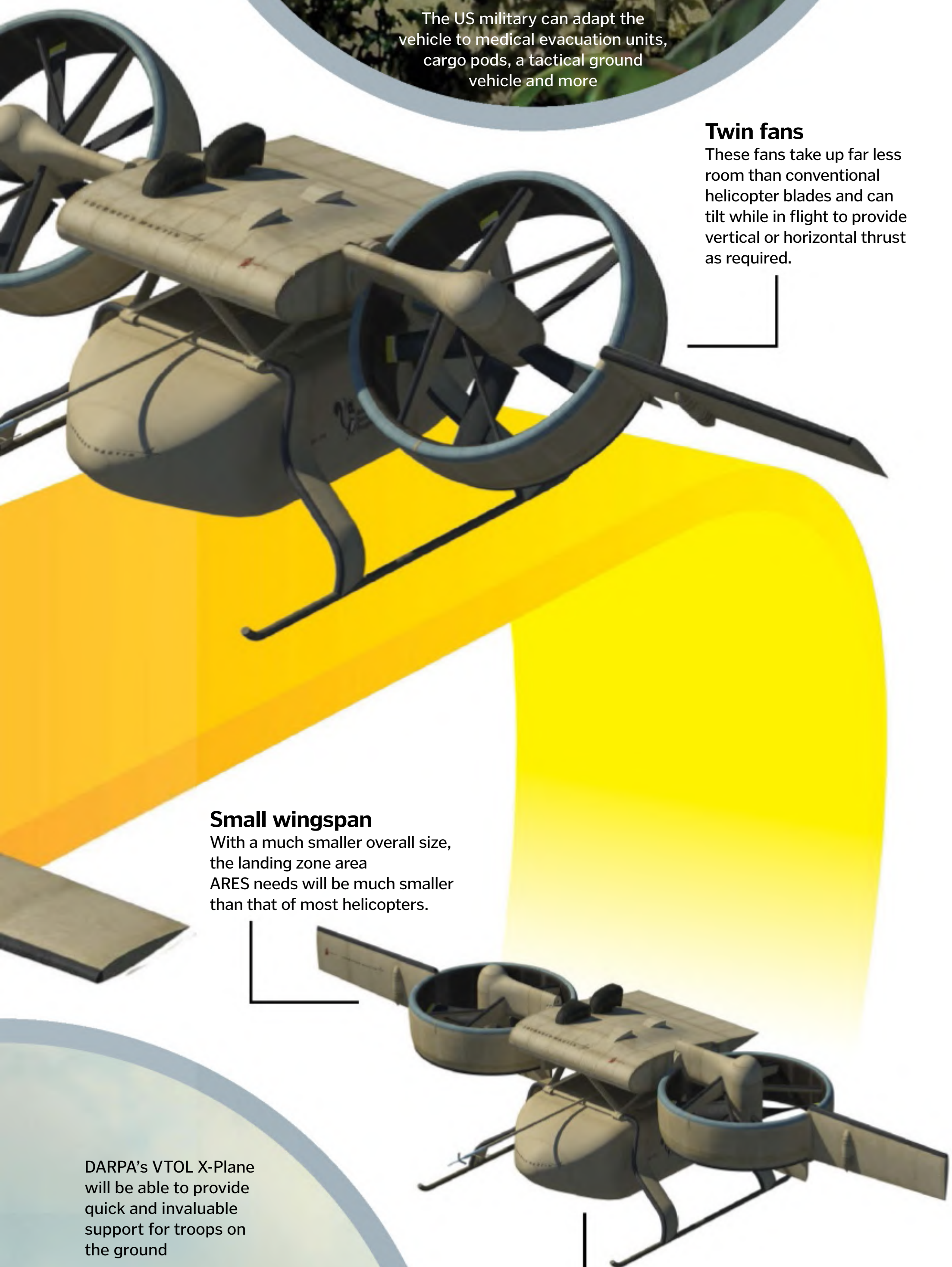
VTOL flight
The VTOL flight module will enable ARES to transition from quick horizontal flight, to hovering, to a vertical landing, all remotely.

Separate flight module
The VTOL flight module is entirely self-contained and separate from the mission module.

Unmanned control
The unmanned aerial system command-and-control interfaces enables remote flight and potential for autonomous control.

Detachable payload
The detachable payload module can weigh up to around 1,361kg (3,000lb) and could be used to transport supplies, house reconnaissance equipment or even evacuate troops.

The US military can adapt the vehicle to medical evacuation units, cargo pods, a tactical ground vehicle and more



Twin fans
These fans take up far less room than conventional helicopter blades and can tilt while in flight to provide vertical or horizontal thrust as required.

Small wingspan
With a much smaller overall size, the landing zone area ARES needs will be much smaller than that of most helicopters.

Autonomous flight
With further development it's hoped that ARES will be able to fly and land all by itself, using sensors to select optimal routes and landing locations.

DARPA's VTOL X-Plane will be able to provide quick and invaluable support for troops on the ground

would be the future. In a world potentially ravaged by nuclear blasts, obliterating any obliging runways, it was thought a craft with the ability to take off and land anywhere would rule the skies. In time, bizarre VTOL aircraft such as the Lockheed XFV Salmon – an experimental fighter – and even the flying saucer-inspired Avrocar were tested by the US military, but most failed and were discontinued. Among the only VTOL aircraft to make it out of the Cold War with flying colours was the BAE Sea Harrier.

Also known as the Harrier Jump Jet, this plane was the first successful VTOL jet aircraft. Four vectoring nozzles direct the jet's engine thrust anywhere within a 90-degree radius, enabling the plane to fly across vertical and horizontal paths, transitioning in mid-air and even hovering.

The Harrier's VTOL ability was ideal for working on aircraft carriers – the floating fortresses of the waves. Its Rolls-Royce turbo fan engine, coupled with unparalleled flexibility and the latest weapons arsenal, made the jet a formidable opponent.

One other vehicle to emerge from the Cold War was the V-22 Osprey. Developed by Bell and Boeing, this vertical-lift transport aircraft is packed with twin tilting rotors capable of both hovering and landing like any helicopter, or transitioning to fly like a turboprop airplane.

With a range of over 400 nautical miles (740 kilometres/460 miles) and the ability to rapidly transport over 30 troops, the Osprey serves the US Marine Corps in key insertion and extraction missions. It even has the ability to fold its 25-metre (82-foot) wingspan away, condensing down to just its 5.6-metre (18-foot) -wide fuselage. This makes it invaluable for storage on aircraft carriers.

With each new generation come fresh challenges for engineers to overcome. Today's military minds face the problems of producing aircraft that are not only cost-effective and incredibly flexible, but also smart. Into the future, contractors and state defence ministries are increasingly turning towards VTOL technology for use with military drones.

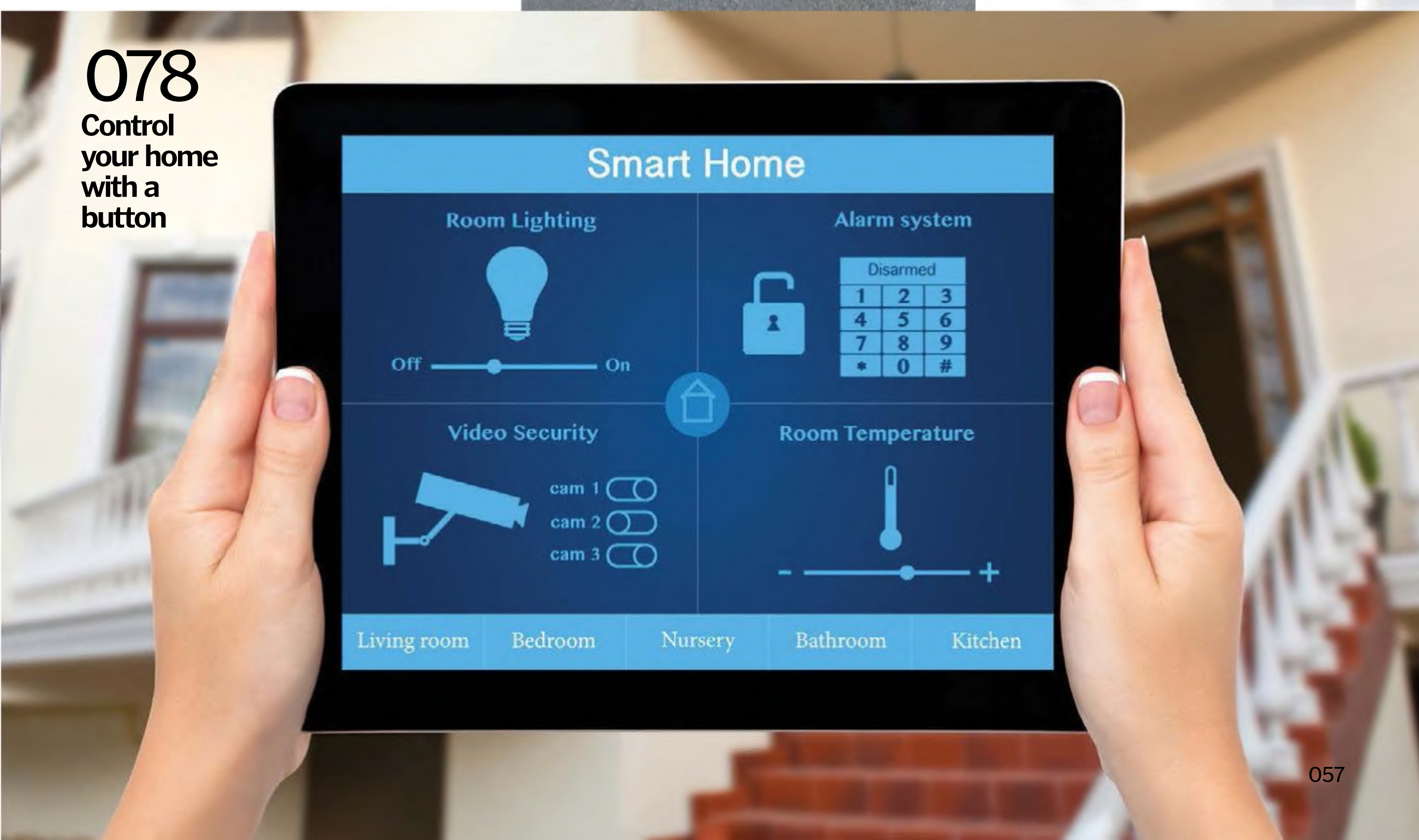
While the computer power behind these machines may be cutting-edge, the physics lifting them into the air and setting them safely back on the ground remain the same.

Either by remote operation or autonomous flight, VTOL drones will be capable of performing a range of transport, reconnaissance, or even offensive missions. We've shown you a few exciting visions – from the best and brightest in the aviation industry – set to launch VTOL technology into the next generation.

EVERYDAY BOTS

058
Robots for fun

066
Driver versus driverless cars



Smart Home
Room Lighting
Off
On
Alarm system
Disarmed
1 2 3
4 5 6
7 8 9
* 0 #
Video Security
cam 1
cam 2
cam 3
Room Temperature
-
+
Living room
Bedroom
Nursery
Bathroom
Kitchen

© Huisten Bosch

FUN BOTS

How robots for fun and leisure will change the way we relax and play in years to come

In case you hadn't noticed, there are robots everywhere. But instead of the malevolent killers we've seen in *The Terminator* or *Battlestar Galactica*, robots are actually making our lives easier, healthier, more fun and even full of inspiration.

Advanced technology in computer processors, materials science and other advanced fields like facial recognition and machine learning are making robots stronger and more versatile, and enabling them to think and act faster than ever.

It's long been the dream of humanity to give the tasks we find too mundane, dangerous or dirty to machines to do for us. Thanks to well-resourced institutions like the US Military and a new breed of tech giants like Google, IBM and Qualcomm, robots are penetrating collapsed buildings after earthquakes to search for survivors, motoring around other planets to unlock the secrets of the universe and even driving cars autonomously.

But less talked about over the last few years is the potential for robots to make our lives simply more enjoyable. Taking cues from the dangerous or monotonous work described above, a new generation of designers has wondered how robots can change the way we play sport, talk to friends or colleagues and even enjoy a drink.

Carrying clubs is a thing of the past when you have a personal caddy robot to do it for you.

The CaddyTrek R2 looks like a well-designed, albeit everyday, golf cart...until it follows you around the course by itself.

Golf caddy

Wheeling your own golf bag is so passé when you can put it on a robotic cart that follows you around

Clip the handset remote to your belt and the CaddyTrek R2 locks on, following you over any course terrain you might encounter. Set it to march a few feet ahead if you prefer or even on to the next tee.

The best part? Forget it's there until you need to select a club (or take a drink from the cup holder).

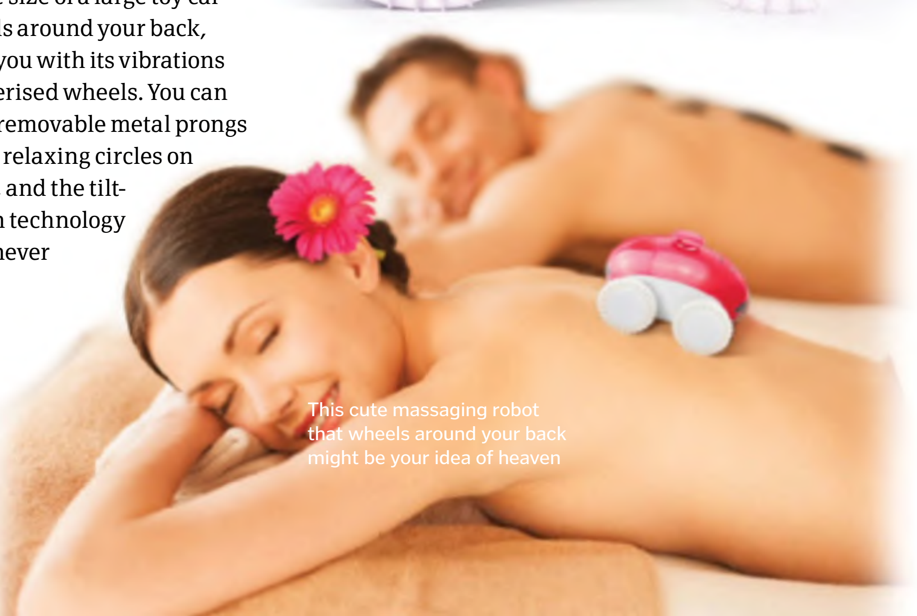
The Double gives you an audiovisual presence from a distance – completely controlled over the internet from wherever you are.

Wheeme massager

Might the never-ending massage (or at least until the battery runs out) be the pinnacle of robotic technology?

If there's one thing we wish could go on forever, it's a massage. But it's rarely the case, and you often find your appointment is finished far too soon.

The Wheeme massager is a cute device the size of a large toy car that crawls around your back, soothing you with its vibrations and rubberised wheels. You can also affix removable metal prongs that draw relaxing circles on your skin, and the tilt-correction technology means it never falls off.



This cute massaging robot that wheels around your back might be your idea of heaven

Telepresence robot

Teleconferencing to a laptop or dedicated video station is so yesterday now that you can control a virtual body in the room

Imagine a Segway, put a video monitor, camera and microphone on top and you have the Double. It gives you the mobility of a video call on a tablet, but you're controlling it from a remote location, driving it around the meeting room or office on the mobile base.

It rolls back to a dock to recharge, and when you're ready for your next interaction, just fire up the app and take command again. Your camera and mike project your image and voice to the Double's display, and it transmits all the video and audio at the other end back to you.

Where else can you be greeted by a robot dinosaur for a hotel stay than Japan's Hen-na Hotel?

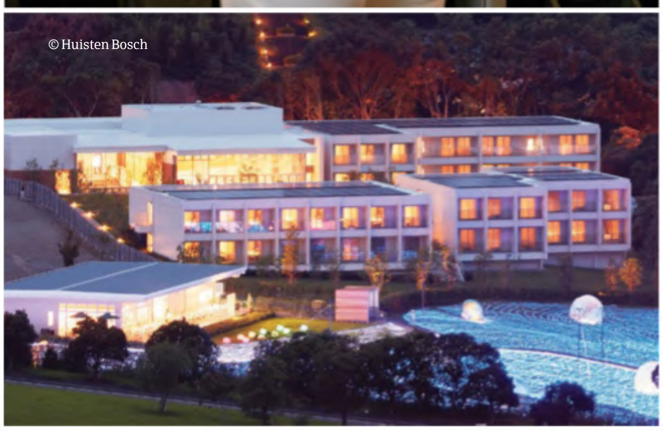
© Huisten Bosch

Robotic hotel

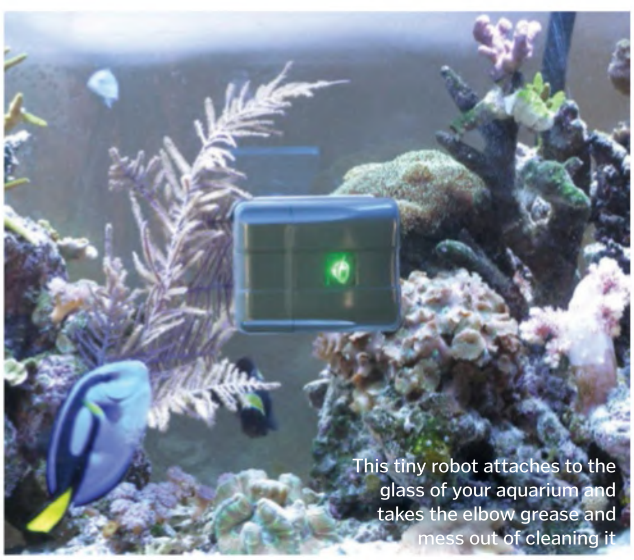
Japan's roboticised hotel offers a thrilling glimpse into a future where domestic help is completely mechanised

When you check into Sasebo's Henn-na Hotel you're greeted by a humanoid robot (or a robotic velociraptor in a wig – seriously). A robot stores your coat. Another takes your bags to your room. The facial recognition system identifies you at your door and unlocks it.

The services are limited so far – they can't provide room service, for example – but the future beckons.



© Huisten Bosch



This tiny robot attaches to the glass of your aquarium and takes the elbow grease and mess out of cleaning it

Robosnail

Your fish might be startled for a while, but they'll appreciate the robot-cleaned glass of their aquarium

In a similar way to how your robotic vacuum remembers the layout of your house, the Robosnail plots and then remembers the size and distance of the glass walls of your aquarium, driving itself around and cleaning as it goes. It will do a lap of the tank once a day.

Watching it work is as welcome as the hours you'll gain by not having to clean yucky algae off the glass yourself.

The Makr Shakr uses a precision work environment and carefully self-programmed movements to bring robotics to a very human institution

Hitchbot

We've always been told hitchhiking is dangerous, but what if a robot could teach us all to be kinder to strangers?

It appears to be a plastic garden bucket with swimming noodles for arms and legs, rubber gloves for hands, rubber wellies for feet and an LED display for a head, but the Hitchbot has journeyed across four countries relying only on the kindness of strangers.

Hitchbot was a social experiment, relying on the kindness of motorists to pick him up from the side of the road, help him tick items off his bucket list and leave him to make another friend.

And he certainly captured imaginations everywhere – when Hitchbot fell victim to vandals in Philadelphia, his many fans on social media reacted were outraged.

Makr Shakr

What's cooler than a hip mixologist at your next trendy event? A robot bartender, of course

A snooty attitude, slack service and tipping might be a thing of the past with the Makr Shakr. The device is a robotic arm kit with a grasping talon that selects and combines ingredients, properly mixes or stirs them and serves your drink with aplomb – just order through the app and watch it go.

The smooth movements of the articulated robot arm are fascinating to watch and look just like a choreographed dance. No word yet on juggling the cocktail shaker though...

Having hitchhiked across several continents, this friendly home-made robot showed the heart-warming kindness of strangers

ROBOT BUTLERS

SAY GOODBYE TO CLEANING

Sit back, relax and let these robots keep your house clean

Suck it up

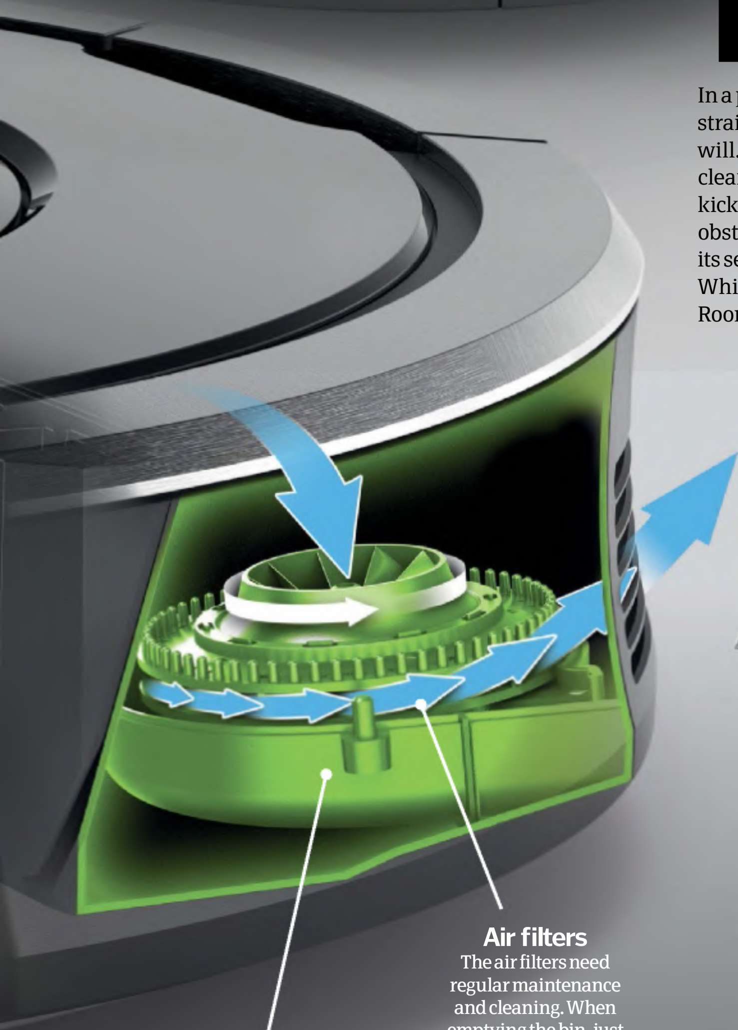
Two brushless rubber extractors with a specially designed tread pattern spin in opposite directions. This creates a sealed channel that concentrates the airflow, which in turn sucks up more dirt.

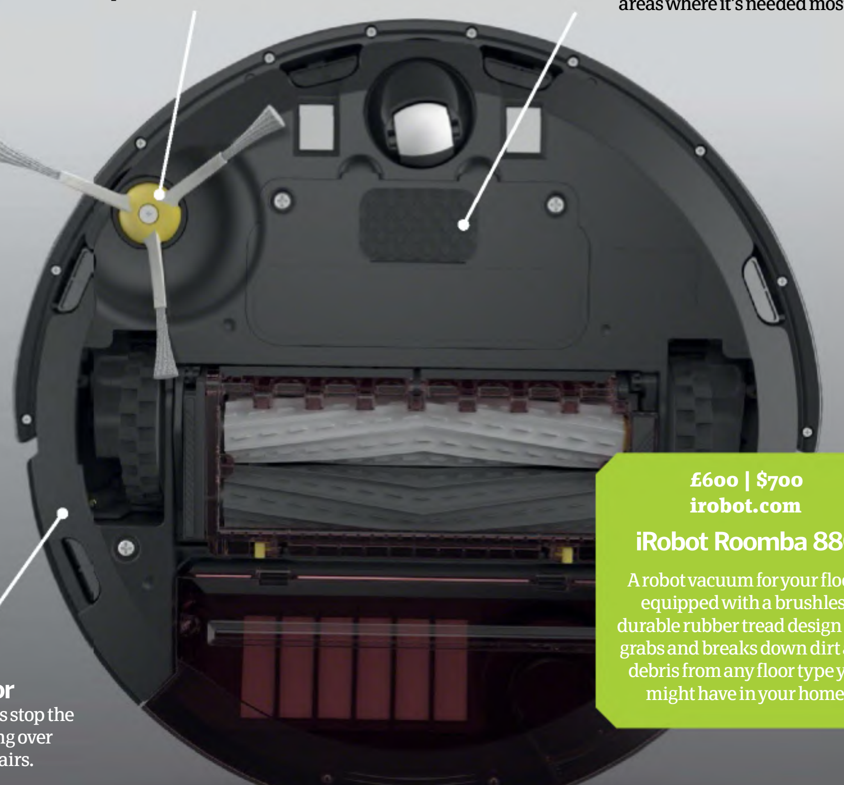
DID YOU KNOW? *The first automatic vacuum was called Trilobite and was released by Electrolux in 1997*

Self control
The integrated clock allows for seven-day scheduling. Simply pick a time and date and the Roomba will automatically clean. When finished it will return to its base to recharge.

This robot sucks

In a perfect world a room would have four straight walls, and perhaps in the future they will. But back in the present the Roomba vaccum cleaner bot has to contend with all angles as it kickstarts into life. Every time it encounters an obstacle its integrated light-touch bumpers tell its sensors that it needs to change direction. While zipping across carpet, or hard floors, the Roomba automatically sucks up all dust and dirt via its brushless cleaning. All manner of debris makes its way into the bin. Dust and dirt sensors seek out areas that have yet to be cleaned, little is left behind. For near total autonomy the Roomba can be scheduled to perform a cleanup as the same time everyday before reporting back for duty as its base recharging station. This is a robot that does what it says on the tin and has a lot in common with the equally impressive Scooba.





Cleans to the edge
Dust and dirt hidden away at wall edges has nowhere to hide. A spinning 3-pronged side brush pushes out any debris, which is then swept into the path of the Roomba's extractors.

Dirt detector
Roomba uses its Dirt Detect Series 2 technology, a set of optical and acoustic sensors, to find dirt and debris and perform concentrated cleaning in the areas where it's needed most.

Air filters
The air filters need regular maintenance and cleaning. When emptying the bin, just tap the Roomba on the side to clean them.

Spot the dirt
The brand new spot option is a great way to target particularly small areas in need of a deep clean.

Cliff sensor
The clever cliff sensors stop the Roomba from falling over edges, such as stairs.

£600 | $700
irobot.com

iRobot Roomba 880
A robot vacuum for your floors equipped with a brushless durable rubber tread design that grabs and breaks down dirt and debris from any floor type you might have in your home.

Throw out your old mop and bucket

There's no need for dirty knees when the Scooba is about. It sweeps, pre-soaks, scrubs and sucks up the dirty water into its two compartment tank. Before the robot takes over it's the human touch that is called into action. Warm water and the included hard floor solution are mixed and added to the tank, ready for action. The Scooba kicks off in a circular motion, sweeping and placing solution onto the floor before heading to the edges of the room. Soft touch bumpers direct the unit round the edges to complete its first pass across the floor. The Scooba goes back for another pass around the room with its scrubbing brush that loosens up any grime for a final pass when the squeegee vacuum sucks up the dirty water. Voila! You now have a clean floor. The beauty of the Scooba is that is does thoroughly clean a floor, unlike the Braava.

Talk back
Need to know what is your robot doing? The information button offers audible cues. Press the button and a voice will tell the user that it has finished its cycle and its tanks needs emptying and battery recharging.

£600 | $600
irobot.com
iRobot Scooba 450
The sister to the Roomba, the Scooba is a robot that scrubs floors clean via a three-way process. It sweeps, soaks and scrubs and vacuums to leave a spotless and germ-free floor.

Stay clean
A dual compartment tank is used when cleaning. One tank contains fresh water and solution. This is applied to the floor as the brush rotates at 600RPM, scrubbing the floor. Dirty water is sucked into the second tank providing a cleaner, more sterile finish.

Clean hard floors with indoor GPS

Indoor GPS
The NorthStar Navigation cube projects a signal onto the ceiling and down to the unit. This determines its location and builds up a virtual map of the room so it knows where it has been and where it needs to go.

Time for change
A set of strong magnets hold the cleaning head in place. The dry mop head uses a push in grip to hold its microfibre cloth. The damp mop head uses Velcro to hold its cloth in place.

Hard floors aren't hard to keep clean but they do need love and attention to stay clean. The iRobot Braava is a simple creature in principle, using a cleaning head with a microfibre cloth. It offers two options, one for dry mopping and the other for the more traditional damp mopping. The dry mop option simple goes forwards picking up dirt and debris. The damp mop mode uses water and cleaning solution, with its cloth to clean the floor.

The Braava doesn't have a set of soft-touch bumpers like the Scooba and Roomba, but it uses the NorthStar Navigation System. This acts like an indoor GPS and maps out the room it is currently in. This tells the Braava where it has been and where it still needs to go to finish its cleaning cycle.

iRobot Braava 380 £280 | $300 | irobot.com

5 ROBOTIC CLEANERS

He's got his 360-degree eye on you

The 360 Eye is another smart invention from Dyson. It is a vacuum cleaning robot that uses a panoramic lens to get a 360° view of the room. This uses complex maths to triangulate its position. This in turn helps determine where it has been and what is left.

Dyson 360 Eye
£750 | $1,250
dysoneye.com

Your robot can clean when you're away

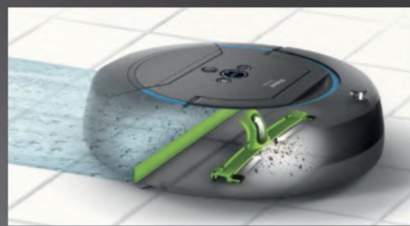
A smarter-than-most vacuum robot due to its ability to be controlled via the companion app. The user can set the robot to clean from almost anywhere. The unit boasts two brushes and combines a curved and straight edge design for corner cleaning.

Botvac Connected
£555 | $850
neatorobotics.com

HOW THE SCOOBA SCRUBS UP

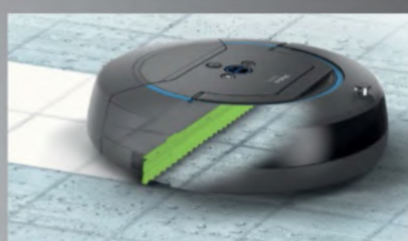
Sensible sensors
The Scooba cleans hard floors. A selection of built-in sensors detect when the surface changes to avoid carpets. Cliff detention sensors ensure that the Scooba stops at sharp drops.

Bumper protection
A light-touch bumper system senses obstacles. When the bumper touches an obstacle it will stop and turn/ reverse and repeats the process until it is clear.



01 Clear the floor!
To begin, the Scooba sweeps up any loose debris and covers the floor in a thin gloss of water.

02 The scrubbing brush
The intense scrubbing brush spins at 600 rpm while the squeegee vacuum sucks up the dirty water.

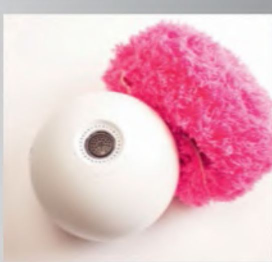


03 Squeegee clean
The squeegee vacuum performs one final suction to get rid of the last dregs of water and leave the floor perfectly clean.

The ME770 is no one-trick pony

The ME770 is a multi-talented hybrid robot that vacuums and mops. It boasts a 460cm squared microfiber mop and a 150cc reservoir to supply moisture for up to 3 hours. The unit can vacuum, mop or combine the two for its hybrid cleaning option.

Moneual ME770 Style
£525 | $808
moneualusa.com



Is it a Furby or a Gremlin duster?

This little 'Gremlin' is a manic fluffy robotic duster that is powered by AA batteries. It is surrounded by a pink microfibre fur coat that rolls around attracting dust and dirt. The coat is machine washable and best suited to wooden and vinyl floors rather than carpet.

Mocoro Robot Cleaning Ball
£25 | $39
firebox.com

Suction cup Spider-Man

No need for a ladder with the Winbot window cleaning robot. It uses a combination of suction pads, tank-style tracks and cleaning pad to clean windows. A selection of sensors identify obstacles and make the W930 turn and change direction to reach into all corners.

Winbot W930
£325 / $500
ecovacsrobotics.com

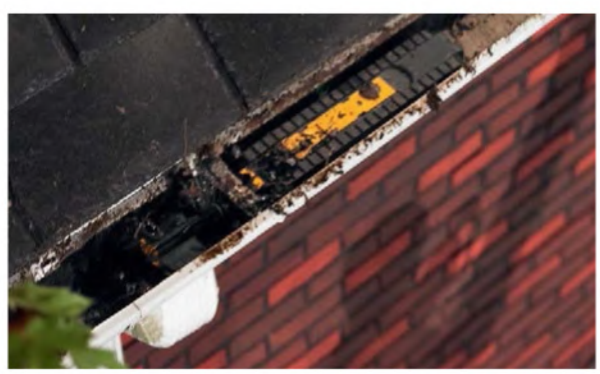
On the move
To move the Looj 330 through a gutter's dirt and debris a pair of rugged, flexible and waterproof polymer treads provide the traction needed to get the job done.

Super spin
The cleaning auger is made up of four ejector components. Two paddles and two wire brushes spin at 500rpm to blast debris away from the house.

The Robot gutter-rat

If there is ever a job where a robot is needed then cleaning gutters is surely it. You still need to climb a ladder to pop the Looj in position, but once there the robot will do the rest. The Looj is a three-part unit, it has the body with its tank tracks which drive it along. The detachable carrying handle also doubles up as a remote control and finally there is the cleaning auger. This is the key cleaning component and has two rubber ejectors and two nylon brushes. The spins at high speed removing dirt, leaves and any other debris from the gutter. It's a simple robot, arguably the simplest of the iRobots range, as there no sensors or bumpers needed to achieve its task. The remote control offers manual interjection allowing the operator to choose spin direction and forward or reverse, nothing more, nothing less. Alternatively, just hit the Clean button and go and make a cup of tea.

iRobot Looj 330
£200 | $300 | irobot.com



Driver versus driverless

How the Audi RS7 driverless car can set a faster lap time on its own than with a human at the wheel

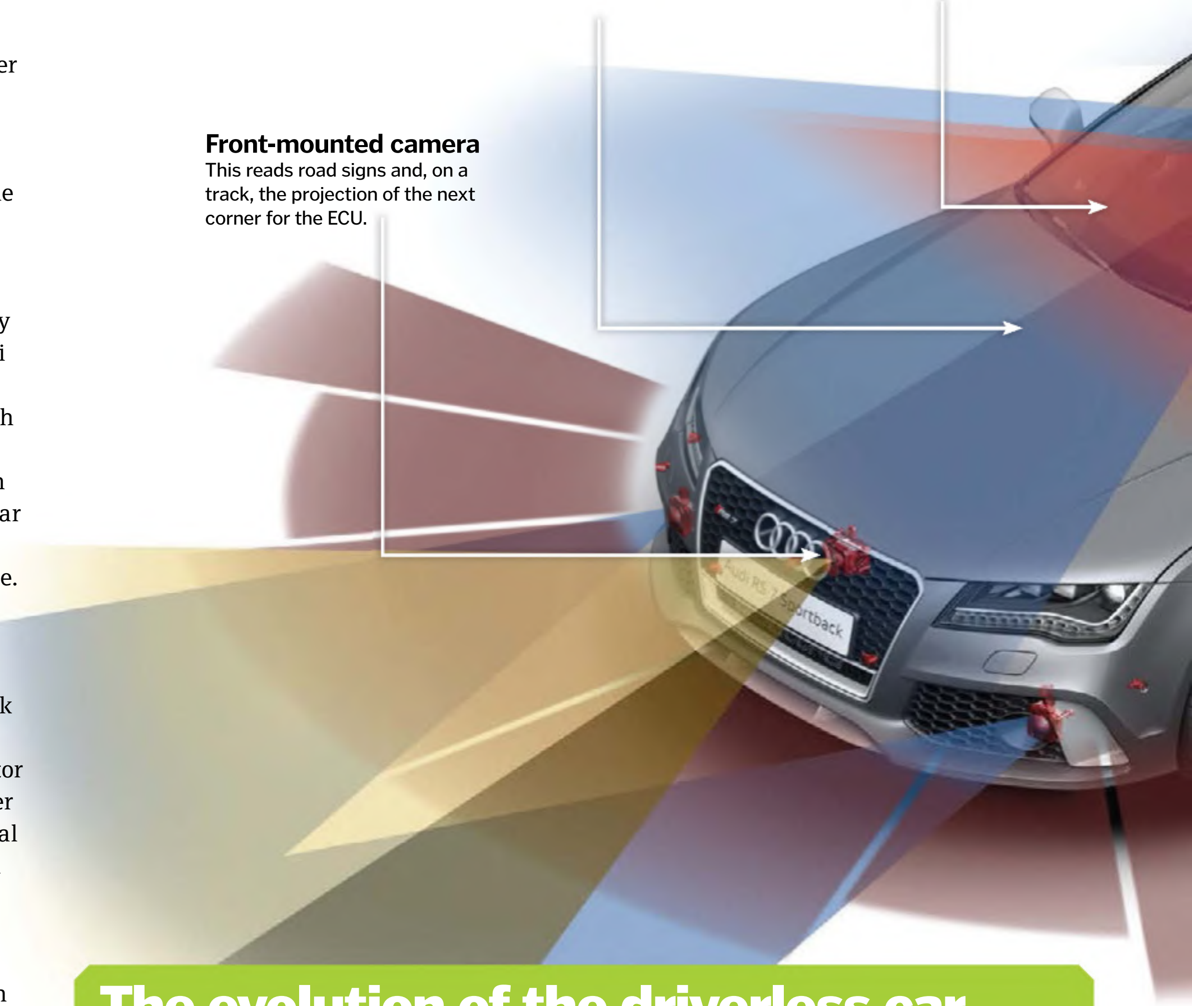
It's the age-old debate: is technology better than the talents of humans? In the automotive world, this argument is fast rearing to a head, with driverless cars now being fully tested on public roads around the world. However, while driverless cars are primarily aiming to be safer than those piloted by a human being, German manufacturer Audi wanted to find out if they are faster, too. The answer to this is the Audi RS7 driverless car prototype, a pumped-up sports car that's been specially adapted with driverless technology.

The RS7 driverless concept works in much the same way as a conventional driverless car currently being developed by other manufacturers, including Toyota and Google. As well as an advanced GPS system with pinpoint accuracy, cameras are placed around the vehicle that 'read' signs and the layout of the road or track ahead. These work in tandem with sensors and radars dotted around the vehicle, which constantly monitor the proximity of the car to the road and other objects. All this information is fed to a central computer, which processes the information and operates the car accordingly.

Where the Audi RS7 triumphs over other driverless cars, though, is not only in the speediness of this entire process, but also in its intelligence. On a regular track, a 'racing line' is taken by drivers to get around the track in the quickest time. This involves using the entire width of the track, braking at the last possible moment before a corner, and keeping the car perfectly balanced throughout. As a thrash around the Hockenheim circuit demonstrated, the driverless RS7 prototype was found to take a very precise racing line on the track, nearly identical to that of a seasoned racing driver. The technology itself isn't without merit, either: a driverless RS7 actually beat a lap time around the Ascari circuit (by two whole seconds!) set by a human being driving an identical car.

The driverless Audi RS7 in action

Here's how the driverless Audi RS7 prototype races round a track without any human input



The evolution of the driverless car

The driverless car industry is fast evolving within the automotive industry. Interestingly, it's not car manufacturers themselves that are at the forefront of the technology either: that accolade goes to technology giant Google, which has developed a unique pod-like vehicle that contains a single cushioned bench inside for all occupants to sit on. Materials used on the Google car are also ground-breaking, with a bendy facia and plastic windscreen implemented to help cushion the blow to a human in the unlikely event of a collision.

Other companies such as Toyota or Volvo have been busy adapting their own conventional passenger vehicles to accommodate driverless tech, but the roof-mounted radar and bigger computers have often proved unsightly and impractical. But there's more: rumours are also gathering pace that Apple is developing its own autonomous vehicle, so watch this space…

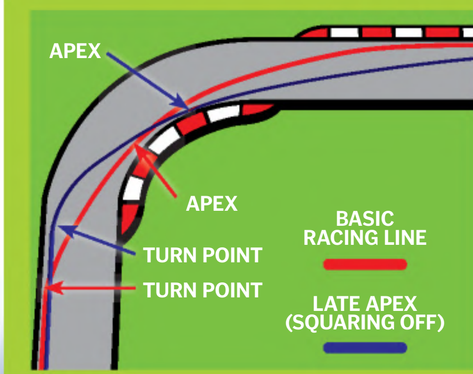

The Tesla model S comes equipped with autopilot

Car controls
The ECU sends inputs to the car's controls, such as steering or throttle input.

Infrared camera
An infrared camera is fitted to enable the car to be driven in darkness thanks to night vision.

Central ECU
This constantly processes all the data from cameras, sensors and GPS, and decides how to control the car as a result.

Ultrasonic sensors
Dotted all around the car, these constantly monitor the proximity of the car to the edge of the track.



Racing line: the quickest way around the track

Race drivers will take a certain line around a race track, in order to complete a lap in the shortest time possible. This is called a 'racing line' and is best described as a route that cuts through corners – without cheating, of course – most effectively, and enables the driver to keep their foot on the accelerator pedal for the longest possible time. Different racing drivers will interpret different racing lines on a track – there is no right or wrong here – though drivers in a world-class competition like Formula One will likely take very similar lines after years of experience and practice on each circuit.

Audi's RS7 driverless concept could be bad news for professional racing drivers in the long term

DRIVING THE FUTURE:

AUTONOMOUS VEHICLES

Self-drive cars use a host of new technology to present a novel concept of travel for road users

All aboard the road train

A further development on the self-drive principle for a single car has already been implemented on a series of vehicles, allowing them to travel autonomously as well as in tandem as part of a group. The concept was an idea borne from the 'SARTRE' project, which stands for Safe Road Trains for the Environment.

Pioneered by Swedish manufacturer Volvo and a group of technological partners, their system uses an array of radar, camera and laser sensors linked together by wireless technology to allow autonomous vehicles to travel together in a train-like platoon.

At the front of the platoon is a dedicated lead vehicle – driven by a professional driver, which is followed autonomously by the trailing vehicles. This is all being done in a bid to reduce the number of road accidents caused every year by driver fatigue.

The technology has already been prove plausible after tests were carried out over 200 kilometres (124 miles) of road near Barcelona, Spain, in May 2012, with three cars automatically following a truck driven by a human being.

The road train successfully melded autonomous technologies with car-to-car 'communication' to ensure that the three self-driven vehicles remained in line throughout the whole test – and crucially, with no collisions at all.

Volvo's SARTRE project in action on a public road

Self-driving trucks

Family cars aren't the only vehicles currently receiving the autonomous treatment. Mercedes is developing the self-drive concept for its fleet of heavy-haulage trucks. And, different to the realms of pioneering software of a Google car, Mercedes is simply evolving some of the tech already found in their new luxury saloons instead.

Cruise control, lane assist, auto braking and stability control – all available on the Stuttgart company's new S-Class – has been synced to a radar on its Mercedes-Benz Future Truck 2025 prototype, which scans the road ahead by up to 250 meters (820 feet) and communicates with the established systems to keep the lorry moving safely, without input from a driver. Developers say the system will drive more economically than a human, saving fuel, while increasing productivity as the vehicle will be able to travel for longer periods than what daily driver limits will currently allow.


Self-drive technology could revolutionise truck transport

The cars of tomorrow won't need steering wheels, an accelerator or a brake pedal; they're autonomous and don't require any human input. What's more is that they are already on the road, with car company Volvo unleashing 100 of them on public roads of Gothenburg, Sweden, in a two-year project.

An autonomous (known as 'self-drive') vehicle works mainly thanks to a wealth of on-board radars, sensors and cameras that continuously 'read' the car's surroundings to build a picture of the road ahead. While radars and sensors monitor everything from the proximity of other cars on the road to the whereabouts of cyclists and pedestrians, a forward-facing camera interprets highway instructions from road signs and traffic lights. All of this information is continuously fed to the vehicle's on-board computer, which uses the data to action appropriate inputs into the car's speed and trajectory within milliseconds. Meanwhile, advanced GPS technology is constantly used to clinically navigate the vehicle along a precise route.

An autonomous vehicle prototype, otherwise known as a self-driving car, looks fairly similar to a contemporary human-driven vehicle. Built-in sensors dotted around the car emit frequencies that bounce back off objects – much in the same way modern parking sensors work on many everyday cars now – to provide a rationale of how close things such as curbs, pedestrians and other vehicles are to the self-driving car. The processing computer and GPS system are stored out of sight, leaving the roof-mounted LIDAR (Light Detection and Ranging) as the only discerning differentiation from the norm.

This rotating camera sends out lasers and uses the reflected light to effectively build a 3D picture of the car's position within the current environment. The information received from these 'bounced' light rays is sent to the main on-board computer. In the cabin, an occupant is treated to a screen showing the route, plus there's an emergency stop button that will immediately pull the car over if needed.

Although technology giant Google has led the way in terms of evolving self-drive technology, automotive manufacturers such as BMW and Nissan have placed considerable resources for research and development into the technology of their own autonomous vehicles. These test vehicles tend to be adapted versions of current human-driven vehicles and as soon as a person touches any of the foot pedals or steering ▶

wheel, the system immediately cedes control back to the driver.

Although Google began its autonomous vehicle mission by adapting already homologated Toyota and Lexus cars as far back as 2010, its latest prototype is arguably the best yet. So far, it has proved to be markedly safe compared to human-input driving, as driver fatigue or alcohol impairment will play no part in getting from A to B.

To heighten safety even further, Google is experimenting with flexible windscreens and a front made of foam-like material to protect pedestrians on impact, should the worst happen. These cars have also been limited to a relatively tame 40-kilometre (25-mile)-per-hour top speed while the project is still in the development stage.

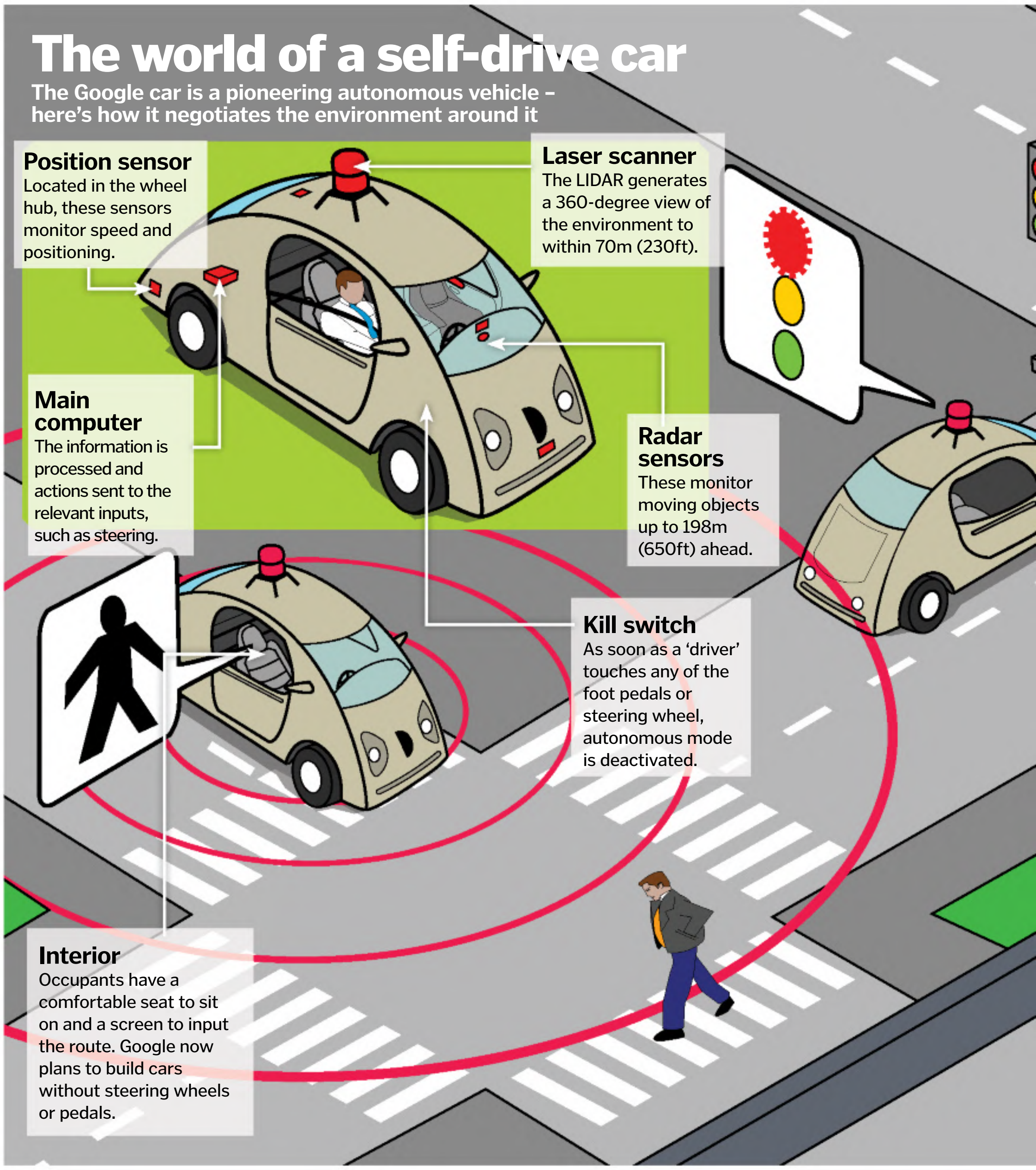
However, while the theory of self-drive cars is relatively straightforward – a computer actions an input for a mechanical device to implement – the unpredictability of hazards when driving is the biggest challenge for an autonomous vehicle to overcome. Much like a human having plenty of practice ahead of their driving test, the process for 'training' self-drive cars is to evaluate every single possible hazard perception scenario that could arise on the road and input them into the car's computer for the best course of action to take.

There are further limitations to the technology. Currently, a Google car cannot drive on a road that hasn't been mapped by the company's Maps system, so taking a self-drive car for a spin around your newly built suburban housing estate could prove somewhat problematic. Also, sensors on the car currently struggle to pick up on lane markings when roads are wet or covered in snow, making autonomous driving in adverse conditions particularly hazardous.

Companies are seeking to address these shortfalls, with safety drivers currently testing their self-drive vehicles in a variety of situations on the road every day and providing feedback on how to further improve the concept. Google even admits that its self-drive prototype is built with learning and development and not luxury in mind, so their own vehicle is currently bereft of any real creature comforts. However, if the blueprint for an autonomous car proves successful, that could well change and we could soon see motorways packed with moving vehicles where every occupant is kicking back and watching a film, checking emails, or reading their favourite magazine.

The world of a self-drive car

The Google car is a pioneering autonomous vehicle – here's how it negotiates the environment around it



Position sensor
Located in the wheel hub, these sensors monitor speed and positioning.

Laser scanner
The LIDAR generates a 360-degree view of the environment to within 70m (230ft).

Main computer
The information is processed and actions sent to the relevant inputs, such as steering.

Radar sensors
These monitor moving objects up to 198m (650ft) ahead.

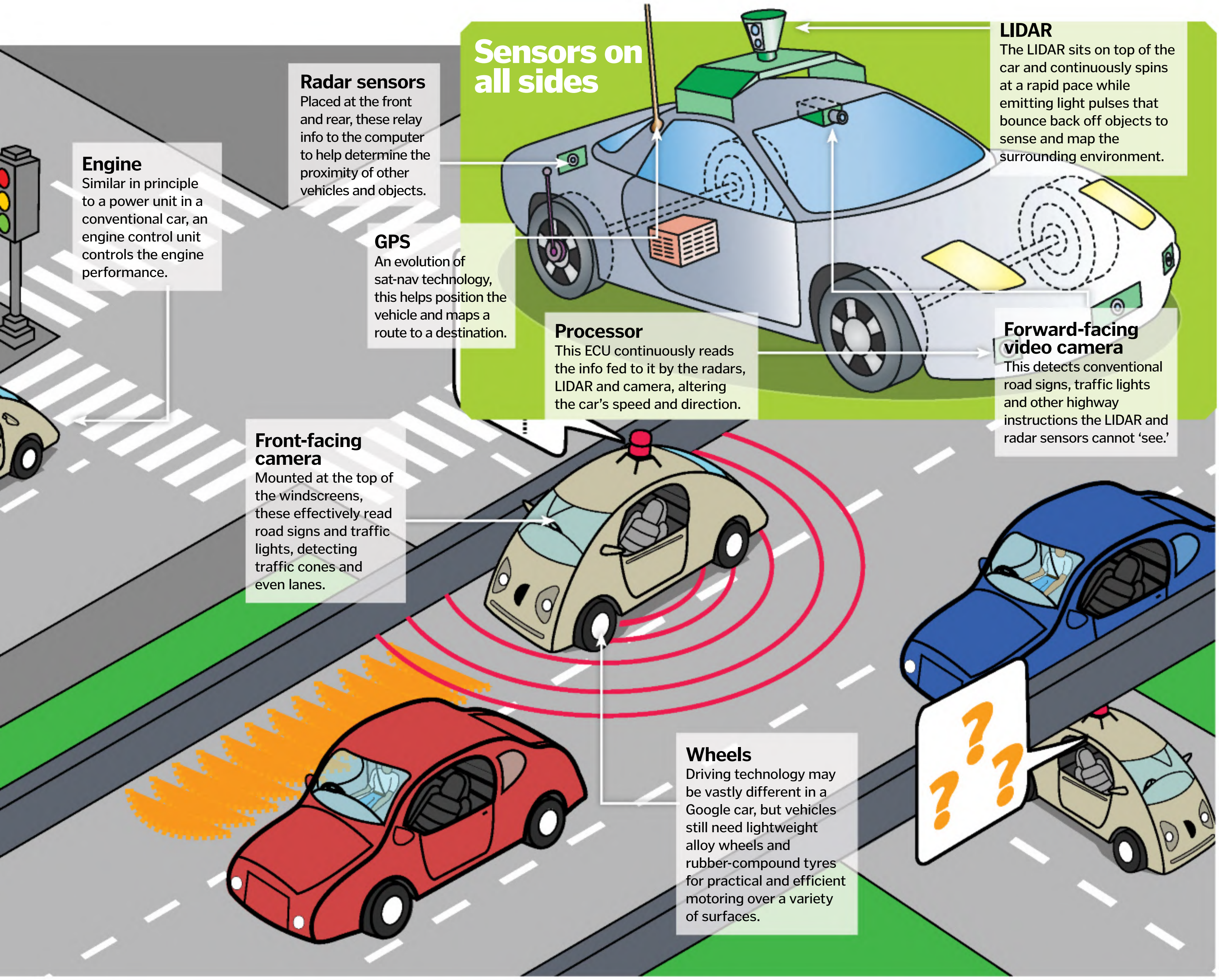
Kill switch
As soon as a 'driver' touches any of the foot pedals or steering wheel, autonomous mode is deactivated.

Interior
Occupants have a comfortable seat to sit on and a screen to input the route. Google now plans to build cars without steering wheels or pedals.

Autonomous tech available now

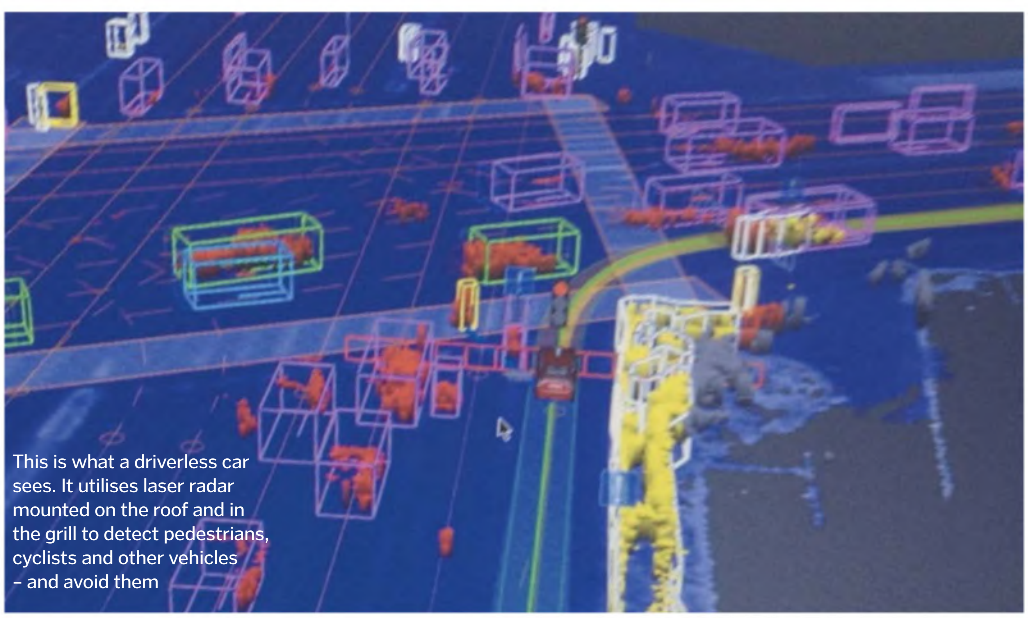
Predictive braking
Available on most modern cars, a radar-controlled Electronic Stability Program (ESP) continuously analyses the traffic ahead and, if the driver fails to react to the proximity of another object, it automatically stops the car.

Lane assist
This stops a vehicle from drifting between lanes. If the front camera detects the vehicle has unintentionally deviated out of a motorway lane, it'll input counter-steer at the wheel to ensure the vehicle returns to its lane.

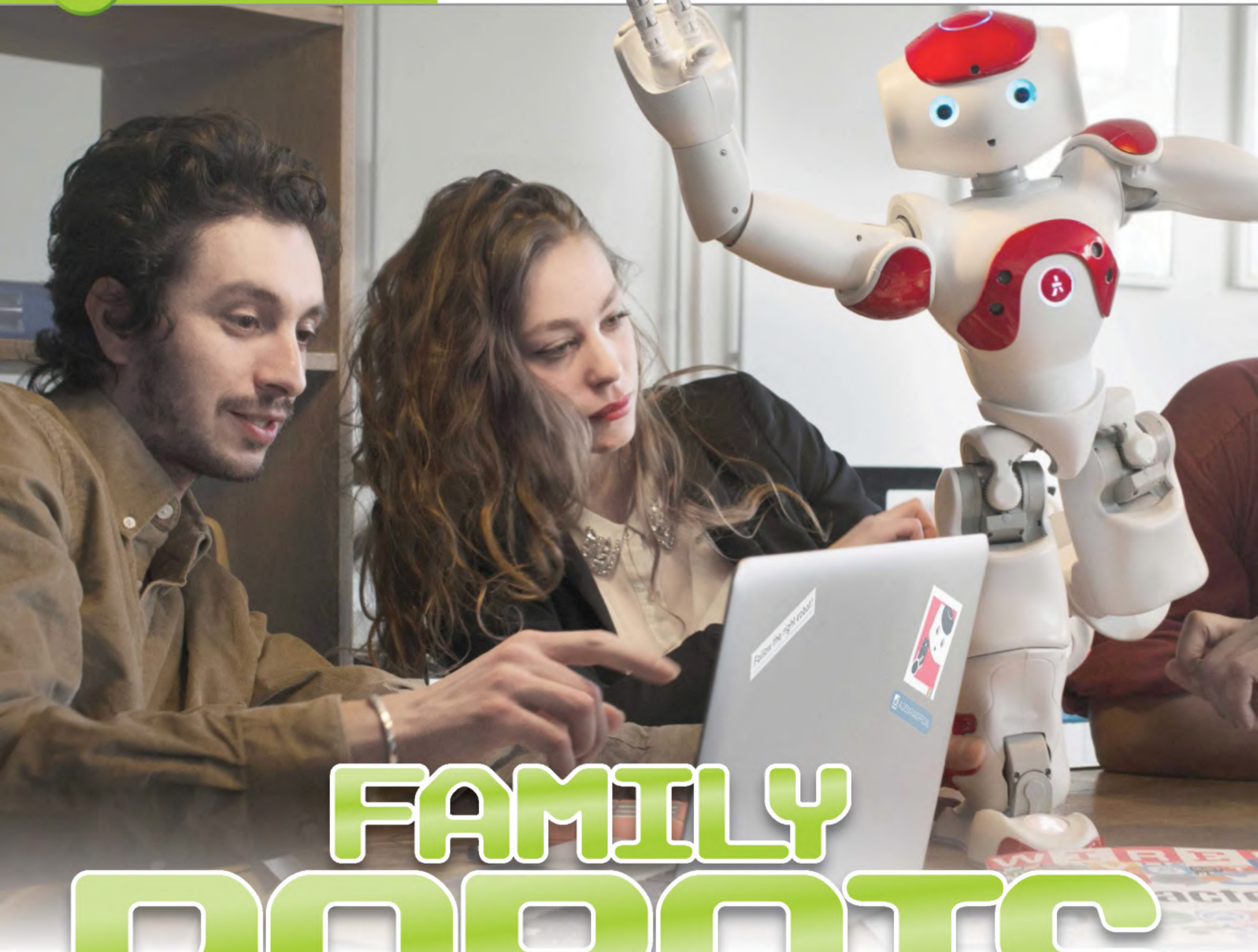


Active high beam control

Porsche and Volvo have introduced active high beam control, which dips the main headlight beam when sensors detect oncoming traffic at night. This avoids dazzling other road users with glare from the main beam.



This is what a driverless car sees. It utilises laser radar mounted on the roof and in the grill to detect pedestrians, cyclists and other vehicles – and avoid them



FAMILY ROBOTS

Meet the robotic helpers who want to work their way into your home and your heart

R2-D2, C-3PO, Rosie Jetson, Johnny 5, Wall-E – popular culture is packed with examples of friendly, sentient robot sidekicks who just want to serve us. Yet despite the human race having sent robots to Mars and beyond, there remains a distinct lack of interactive robots in most of our daily lives. But that might finally be about to change thanks to a few key technological developments.

Of course, NASA has more money to throw at robotics than us mere mortals. Today, however, the processors, sensors, tiny motors and other components involved are vastly improved and have become much cheaper to produce, thanks largely to the smartphone revolution. Advances in 3D printing and the open source software movement have dragged costs down even further, to the point where emerging social robots are just about in the realm of what is typically seen as affordable – at least for those who can comfortably purchase high-end personal computers or used cars.

A second, arguably even more important, barrier is gradually being overcome too: humanising the technology. It's a fact that, for every adorable R2-D2 in our collective memories, there's a HAL 9000 or a Terminator hell-bent on driving us to dystopia. Stories like *I, Robot* and *The Matrix* have conditioned us to fear a global cybernetic revolt where robots take over our lives and control our every move.

Technology is being developed to enable robots to recognise and respond sensitively to

our emotions. They can perform gestures and expressions that mimic ours – like sagging shoulders or a curious head tilt –making it easier for us to form bonds with machines.

Unlike fabled "robot servants", family robots are intended to engage, delight and enrich our lives. They will help keep us organised with reminders about appointments or medication doses. They will provide genuine companionship and help the elderly live independently for longer by being present and ready to call for help if needed.

"The most important thing for us is to fight loneliness," explained Bruno Maisonnier – founder of Aldebaran Robotics, a French company that produces a number of social robots including Pepper and NAO – in an interview with Yahoo Tech. "If you're angry and losing your humanity, NAO can detect that and do something to help you bring it back. It actually helps humans be more human. That's the part nobody expects."

JIBO

The most adorable pile of electronics ever just wants to be part of your family

JIBO – the runaway crowd-funding success story that reached its goal within four hours – is pegged as "the world's first family robot" and will start shipping in late 2015. Standing stationary at a diminutive 28 centimetres (11 inches) tall, he eschews the traditional humanoid form in favour of something altogether more Pixar flavoured and he simply wants to make your home life run that little bit more smoothly.

Reading his surroundings with a pair of hi-res cameras and 360-degree microphones, JIBO recognises faces and understands natural language. In-built artificial intelligence algorithms help him learn about you, adapt to your life and communicate with you via a naturalistic range of social and emotive movements, screen displays, gestures and sounds.

JIBO's skillset

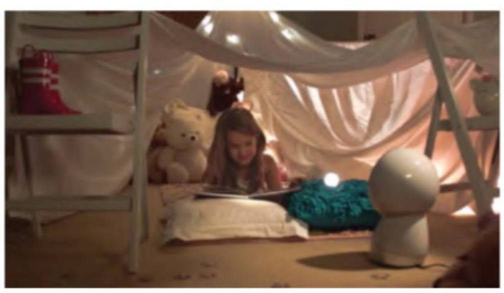
The many and varied roles of the "world's first family robot"

Communication facilitator

JIBO makes video calls with absent friends and family feel like you're actually in the room together. As the incoming caller, you can direct him to look at a specific person with one tap of your finger and his see-and-track camera will follow them naturally as they move around. When a new person chimes in, JIBO will automatically turn to them.

Photographer

Via his dual hi-res cameras, JIBO can recognise faces, identify individuals and track any activity that is going on around him. Using natural cues like movement and smile detection, for example, he can decide the optimal moment to snap a picture, or will obediently oblige your voice command to take the shot.



Storyteller

Story time with JIBO is just as entertaining as it is with a parent. He regales his playmates with tales embellished with sound effects, animated graphics and expressive physical movements and – using his sensors and special interactive apps – reads and responds to the reactions of his enthralled audience.

Personal assistant

JIBO's camera software recognises each member of your household, enabling him to be a hands-free personal assistant to everyone – delivering reminders and messages at the right time to the right person. When you're busy, he'll search the internet for anything you ask for. He'll even log your takeaway order and place it!

NAO

Say hello to the friendliest social humanoid, created for companionship

NAO is one of the most sophisticated humanoid robots ever built, not to mention one of the cutest. Standing 58 centimetres (23 inches) tall, he is completely programmable, autonomous and interactive. He can walk, dance, sing, hold a conversation and even drive his own miniature robot car! Currently in his fifth incarnation – known as NAO Evolution – he has, in fact, been constantly evolving since he burst on to the scene in 2006.

NAO reads his surroundings via sensors including cameras, microphones, sonar range finders and tactile pads. Today he can recognise familiar people, interpret emotions and even form bonds with those who treat him kindly – roughly mimicking the emotional skills of a one-year-old child.

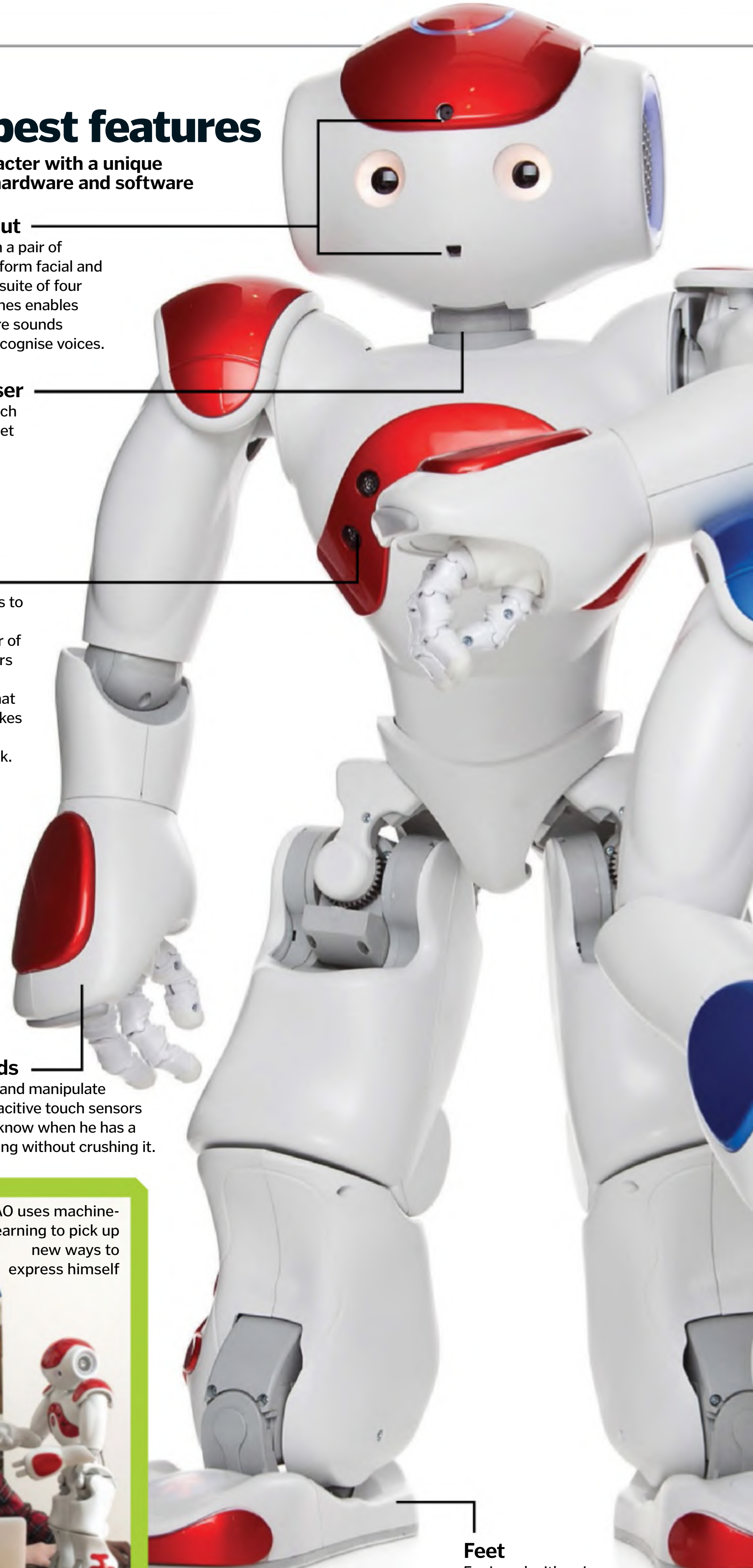
With a battery life of more than 1.5 hours and an electrically motorised body whose joints give him 25 degrees of freedom, he can navigate his world avoiding obstacles, pick himself up if he falls, and – most importantly – bust out impressive dance moves.

A key feature of NAO's programming is the ability to learn and evolve. Over 500 developers worldwide are engaged in creating applications to run on his NAOqi 2.0 operating system and three gigabytes of memory. Being autonomous, NAO can download new behaviours on his own from an online app store.

Today, NAO is the leading humanoid robot used in research and education worldwide, with more than 5,000 NAO units in over 70 countries, according to his creators Aldebaran Robotics.

NAO's best features

He's a little character with a unique combination of hardware and software



Audiovisual input

NAO is equipped with a pair of cameras and can perform facial and object recognition; a suite of four directional microphones enables him to decipher where sounds originate from and recognise voices.

Vocal synthesiser

Includes text-to-speech capabilities for internet recital; able to communicate in 19 different languages.

Sonar system

NAO judges distances to nearby objects and obstacles using a pair of ultrasonic transmitters (top) and a pair of receivers (bottom) that analyse the time it takes for inaudible sound pulses to bounce back.

Prehensile hands

Enable NAO to grasp and manipulate objects. A trio of capacitive touch sensors in each hand let him know when he has a good grip on something without crushing it.

Feet

Equipped with noise damping soles for a quiet walk and tactile sensors for interacting with objects and obstacles.

NAO's sensitive side

NAO reads human emotions by analysing a set of non-verbal cues. Using data from his cameras, microphones and capacitive touch sensors, he interprets things like how close a person stands, how animated they are, how loud they're being compared to their usual level, what facial expression they're wearing, what gestures they're making and how tactile they are being.

His understanding of emotion has been cultivated using professional actors to help him recognise these non-verbal cues, and he is currently able to accurately detect emotions about 70 per cent of the time. He is programmed with a set of basic rules about what is 'good' or 'bad' for him which help him decide how he ought to respond.

NAO expresses his own emotions via a combination of lifelike postures and gestures (for example, he will cower and shake if he is afraid), vocalisations and sound effects, and coloured lights in his eyes. Using machine-learning algorithms, he picks up new ways to express himself from the people he interacts with – just like a baby.

NAO uses machine-learning to pick up new ways to express himself

DID YOU KNOW? 28% of people surveyed wouldn't pay over $1,000 (£650) for a domestic robot, and 29% wouldn't buy one at all

"A key feature of NAO's programming is the ability to learn and evolve"

ROBO-HELPERS

Check out how these robot servants could help make household chores a thing of the past!

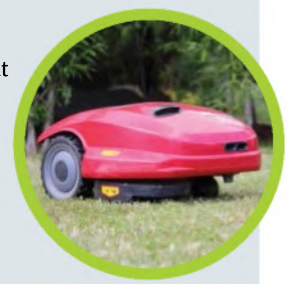
Floor cleaning

Automatic vacuum cleaners like iRobot's popular Roomba size up a room and navigate the floor in a random motion as they clean. Roomba's younger sibling, Scooba, can vacuum and wash non-carpeted floors simultaneously, and both devices can be set to clean on a schedule.

Getting up

Good news for those who struggle to get up in the morning: the Clocky robot alarm clock gives users one chance to snooze before it rolls off the bedside table and finds a hiding place – different each day – forcing would-be slumberers to chase it down.

Garden upkeep



Cheating teenagers everywhere out of a little extra pocket money, Robomow works like an outdoor version of the Roomba to keep lawns in pristine condition. It handles all grass types, slopes up to 20 degrees and knows to head for cover as soon as it detects any rain in the air.

Laundry maid

Researchers at UC Berkeley programmed research and innovation robot PR2 to carefully fold fresh laundry back in 2010. Fast-forward four years, and they had it taking dirty laundry to the machine and setting it going too. The catch? Your own PR2 would set you back $400,000 (about £260,000)!

Robo Butlers

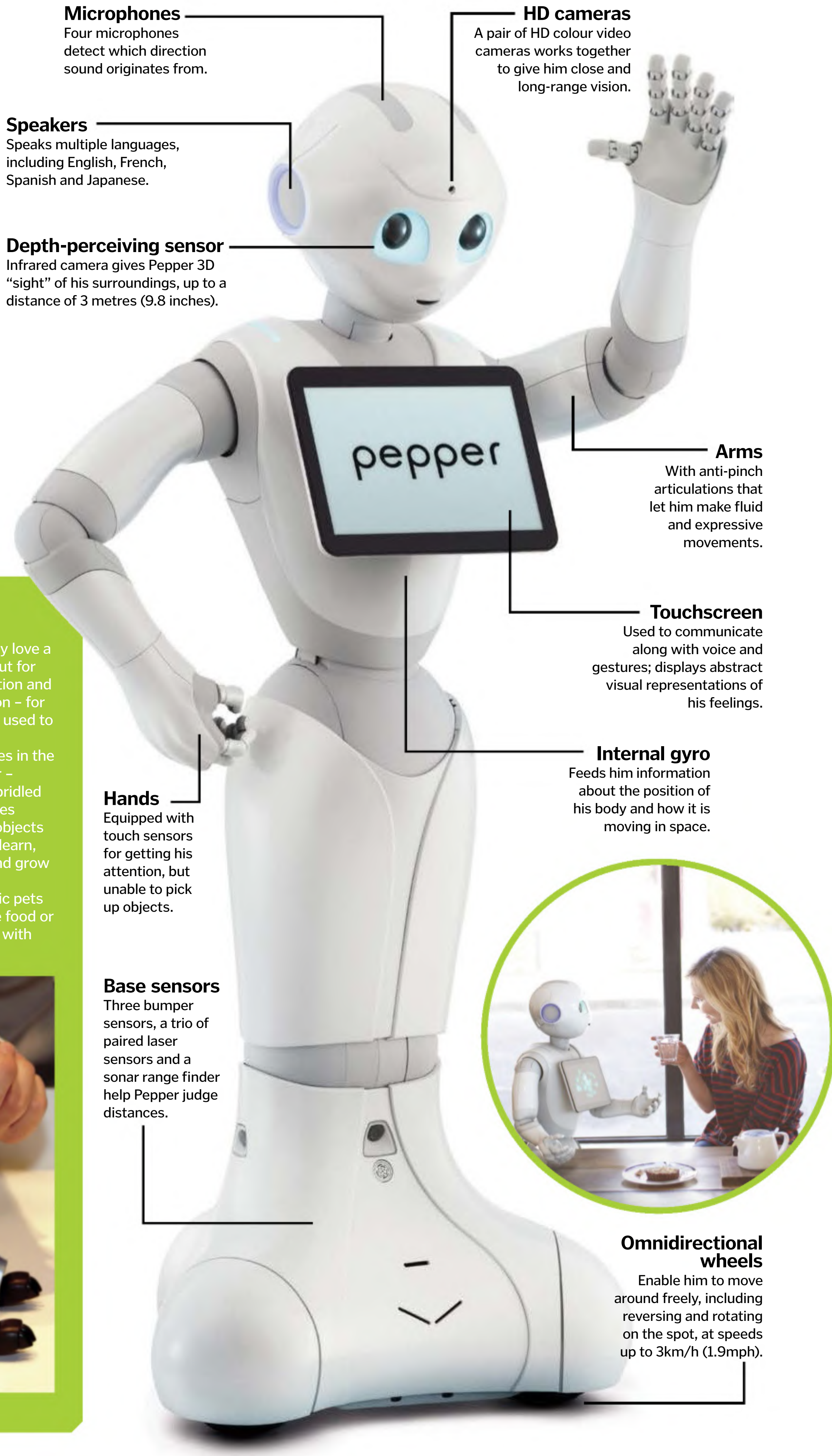
A recent PR stunt from the makers of the Wink home automation app touted a revolutionary (and fake!) Robot Butler but, despite a few early inroads like BrewskiBot – a hefty rolling fridge that is designed to shuttle drinks – robotic butlers have yet to be commercially realised.

PEPPER

The perfect houseguest: a conversationalist who'll adapt to your mood

Pepper is the first autonomous social robot designed to live with humans. Like us, he reads emotions by analysing facial expressions, vocal tone and gestures, and engages people in meaningful mood-appropriate conversations. He exudes 1.2 metres (four feet) "of pure style", rolling around autonomously for up to 14 hours at a time, and even knows when it's time to plug himself in for a recharge.

Pepper learns from his interactions with humans and uploads his generalised findings to the Cloud so that he and other Peppers can evolve as a collective intelligence. This is welcome news because, so far, his jokes are pretty lame! Since June 2014 Peppers have been used in SoftBank Mobile stores in Japan to greet and assist customers. The first 1,000 models were made available to consumers in June this year and sold out in under a minute.



Robotic pets

You may think it's crazy to suggest you could possibly love a robot as much as you love your real-life dog or cat. But for some people, robotic pets offer a chance for connection and companionship that they might otherwise miss out on – for example, older people who are less mobile than they used to be or children with life-threatening allergies.

They've come a long way since the alien-like Furbies in the late 1990s and the multi-functional dogs like Zoomer – which hurls itself around with all the "grace" and unbridled energy of a puppy. Robotic pets have motorised bodies equipped with sensors to detect things like motion, objects and voice commands. Some even have the ability to learn, respond to kindness, develop a unique personality and grow through various life stages, like baby dinosaur PLEO.

Of course, there are the added benefits that robotic pets will never ruin your furniture, don't require expensive food or vet visits and won't demand walks when it's pouring with rain! All the fun – none of the inconvenience!

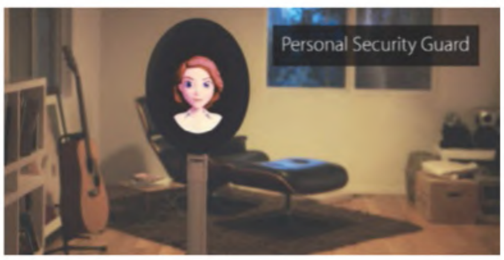
All the fun – none of the clean up!

PERSONAL ROBOT

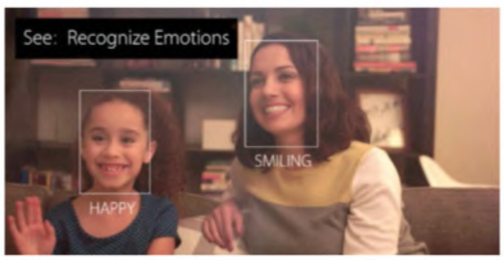
Assistant, security guard, and home automation system all rolled into one

Personal Robot is a smart personal assistant equipped with a heavy dose of artificial intelligence (AI). The 1.2 metre four-foot tall robot consists of a sturdy, wheeled base and a sensor-packed interactive screen carried by a telescopic strut. It navigates its environment autonomously, using in-built mapping algorithms to build and memorise the floor plan.

The gender and characteristics of each Personal Robot are customisable and its AI algorithms bring together face, emotion and object recognition, natural language processing and wireless connectivity to allow it to interact seamlessly with its environment and owners. Its creators, New York City start-up RobotBase, expect to start selling the robot by the end of 2015.



Personal security guard
Sends you updates and real-time video feeds so you can check on your home and pets while you're gone.

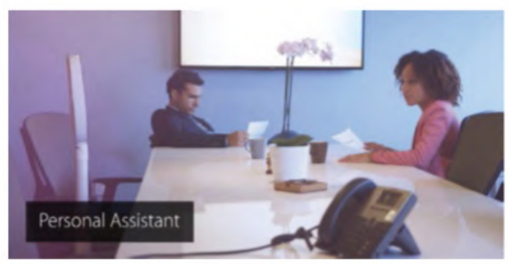


Emotionally intelligent
Recognises human emotions by interpreting facial expressions with artificial intelligence (AI).

Recognises objects
Identifies familiar household objects and wirelessly connects to and controls compatible appliances.

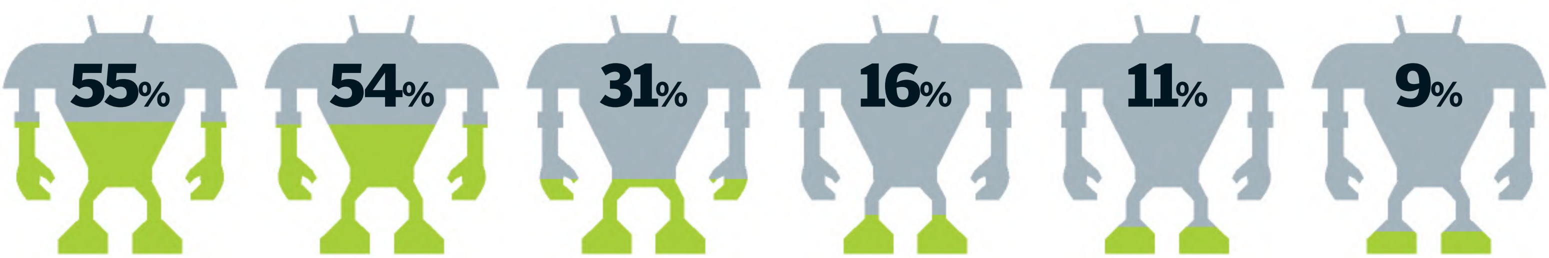
"Feels" the environment
Uses a suite of sensors to monitor variables like temperature, humidity and air quality.

Personal photographer
Recognises good photo opportunities and leaves you free to join your friends in the frame.



Personal assistant
Provides wake-up alarms, appointment reminders, fashion advice, fact-checking and business information.

Survey respondents' likelihood of using a robot for various tasks



Heavy lifting | Home security | Ironing clothes | Preparing food | Elderly care | Babysitting

HOMES OF THE FUTURE

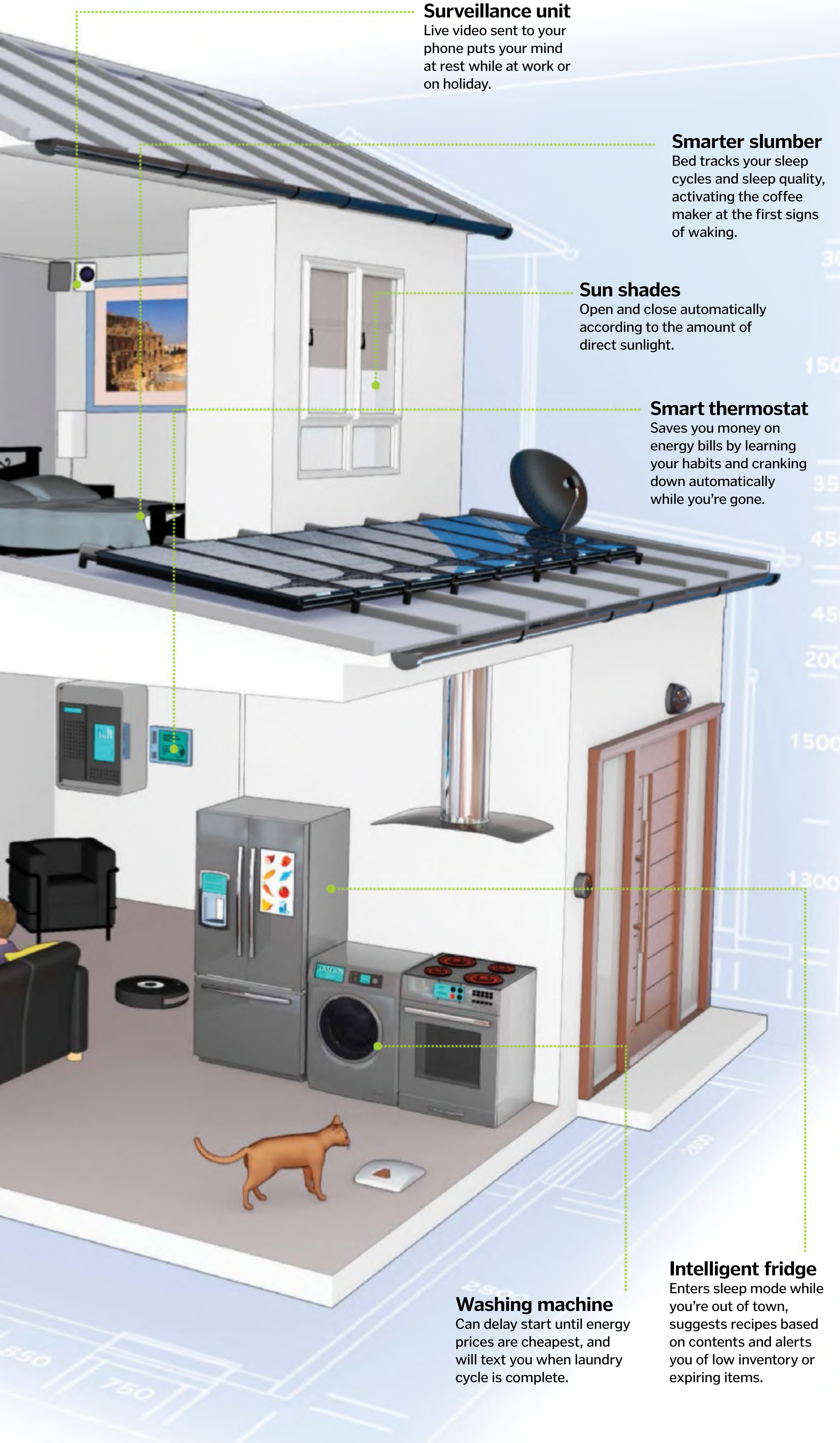
Now that smartphones are everywhere, get ready for the smart home!

We've all been there. Halfway to the airport and suddenly gripped by the unshakable fear that we've forgotten to switch off the oven or lock the windows. With a smart home, you can put your mind at rest and fix any little oversights, all from your phone as you speed toward your flight.

In a smart home, all the electronic devices are connected to one another in one controllable network, allowing inhabitants to interact with their homes like never before and offering greater comfort, convenience, personalization, energy savings and opportunities for fun!

Want your coffee maker to crank up downstairs as soon as you throw back your sheets? A smart home will let you arrange that. Want to start the bread maker churning and the pool heating as you leave the office? You can do that too. Want your home to learn your habits and help cut your energy consumption, or to notify you if it senses anything untoward like an intruder? No problem at all.

The basis for all these technological advances is the 'Internet of Things' – the exponentially expanding web of devices that are connected to the internet, allowing them to talk to each other and to you, transforming the way we live. ▶



Surveillance unit
Live video sent to your phone puts your mind at rest while at work or on holiday.

Smarter slumber
Bed tracks your sleep cycles and sleep quality, activating the coffee maker at the first signs of waking.

Sun shades
Open and close automatically according to the amount of direct sunlight.

Smart thermostat
Saves you money on energy bills by learning your habits and cranking down automatically while you're gone.

Washing machine
Can delay start until energy prices are cheapest, and will text you when laundry cycle is complete.

Intelligent fridge
Enters sleep mode while you're out of town, suggests recipes based on contents and alerts you of low inventory or expiring items.

Talking to your tech

Tracking the growth of the Internet of Things

20% NUMBER OF USA ADULT INTERNET USERS WHO ALREADY OWN A DEVICE THAT CONNECTS THE PHYSICAL ENVIRONMENT TO THE INTERNET [FORRESTER]. THIS WILL RISE TO 50% BY 2020 [PARK ASSOCIATES]

1.5 million NUMBER OF FULL HOME AUTOMATION SYSTEMS INSTALLED IN THE USA IN 2012 [ABI RESEARCH]

224 million NUMBER OF HOMES WORLDWIDE (1 IN EVERY 8.5 HOMES) THAT WILL HAVE SOME SORT OF SMART HOME TECHNOLOGY INSTALLED BY 2019 [STRATEGY ANALYTICS]

10% NUMBER OF US HOMEOWNERS AGED 25-34 WHO OWN AT LEAST ONE SMART ENERGY DEVICE [PARK ASSOCIATES]

1 in 9 (11%) NUMBER OF UK HOUSEHOLDS THAT WILL BE USING AT LEAST ONE SMART DEVICE BY THE END OF 2014. THIS NUMBER WILL JUMP TO OVER 1 IN 4 (27%) JUST FIVE YEARS FROM NOW [STRATEGY ANALYTICS]

$7.8 billion (£4.6 BILLION) PREDICTED SIZE OF THE DIY SMART HOME MARKET BY 2019, UP FROM $1.3 BILLION (£770,000) TODAY [NEXTMARKET INSIGHTS]

150 NUMBER OF INTERCONNECTED DEVICES IN USA'S 'SMARTEST' HOME [HUFFPO VIDEO INTERVIEW WITH OWNER]

20% AMOUNT AN AVERAGE USER COULD SAVE ON THEIR ENERGY BILL BY INSTALLING A NEST LEARNING THERMOSTAT [NEST]

7% THE NUMBER OF US HOMES WITH PROGRAMMABLE THERMOSTATS JUMPED BY THIS MUCH BETWEEN 2012 AND 2013 [CONSUMER ELECTRONICS ASSOCIATION]

£234 OR $393, AVERAGE TECHNOLOGY SPEND OF UK SMART-HOME OWNERS, LESS THAN HALF THAT OF THEIR US EQUIVALENTS (£517 / $868) [STRATEGY ANALYTICS]

Automated home electronics have been on the scene for decades, but only recently have they been able to begin talking to one another and functioning in concert. That's largely thanks to the advent of efficient low-cost wireless protocols – think Wi-Fi, Bluetooth and mobile phone networks – in the early-2000s, which use radio waves to transmit messages wirelessly.

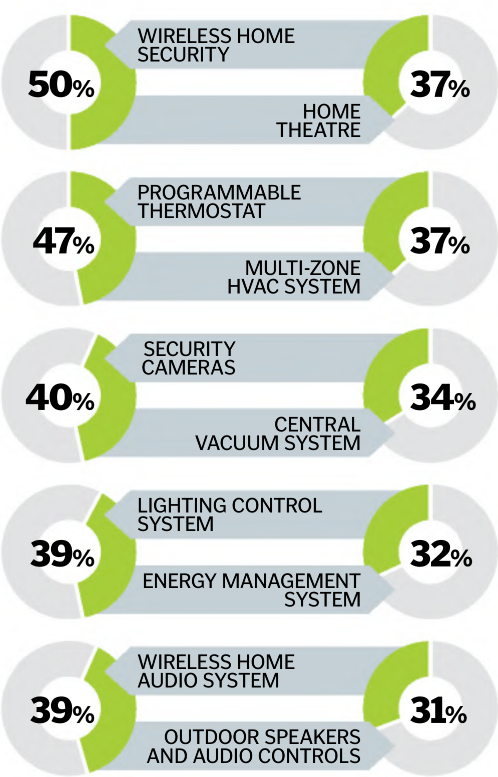
ZigBee and Z-Wave are similar protocols that can be thought of as low-power, short-range versions of Wi-Fi. They are ideal for use inside the smart home because they're optimised for transmitting small amounts of data – like messages to and from smart devices – through walls and furniture, over the range needed for a typical household.

Smart devices are connected via these wireless networks to a central hub where they can be controlled with a tablet or smartphone. They can also be programmed to carry out any action based on the logic command 'If This Then That', or IFTTT (rhymes with lift). IFTTT lets you dictate what action a device should take for a given stimulus.

For example, announcing to your TV, "It's movie time", might lower the shades, dim the lights, activate your surround sound system and fire up the popcorn maker. Now that's smart.

Homeowner wish list

Top ten most coveted smart technologies*



*data from National Association of Home Builders

THE SMART OUTSIDE

Sprinklers
Override their program to turn off when it rains and on if the soil becomes too dry.

Pool party
Water temperature can be set on your drive home, ready for your evening dip.

Attentive awnings
They adjust themselves automatically as the Sun moves overhead.

Surveillance system
Keeps an eye on the kids in the pool, and knows the difference between pets and an intruder.

Occupied home simulator
Activates lights and shades to give an impression of habitation while you're away on holiday.

Until recently, smart homes have mostly been viewed as quirky playgrounds reserved for the super-rich and diehard *Jetsons* fanatics. In the US today, less than one per cent of homes have a full automation system installed, but the picture is changing rapidly. Why?

"What's happening is there's a shift from that past market – which required a professional installer, and more recently a service-provider subscription – to what we're starting to see now: the roll-out of what we call DIY smart homes", explains chief analyst and smart-home expert Michael Wolf of NextMarket Insights in Seattle.

The majority of new smart objects are designed to plug-and-go. New smart-home residents can shop around for devices that best meet their needs, download the apps that make them run, stitch them all together through their humble smartphone, and save themselves a fortune in the process. "That's where we see the potential for much greater adoption, because the barriers in terms of cost and heaviness of the install start to go down", says Wolf.

In 2014, several tech giants rushed to make their first forays into the smart-home market, steering it firmly toward the mainstream. In January 2014, Google acquired Nest Labs – founded by iPod designer Tony Fadell – for £1.9 billion ($3.2 billion). Nest's most popular product, the Learning Thermostat, responds to your routines and preferences, turns itself down when it notices you're away, helping you save energy.

Elsewhere, Microsoft formed a partnership with smart hub and device company Insteon in 2014, while Apple announced that its own Siri-integrated smart-home platform HomeKit would debut as part of the iOS 8 release across iPhones, the iPod touch and iPads.

So if smart homes offer improved comfort, convenience, security and environmental credentials, for an affordable price, what's the catch? For one thing, the explosion of new products, all running on different protocols, can be hard to integrate; less tech-savvy consumers might want to hold off a year or so while the industry reaches a better consensus.

More troubling is that smart homes, like any internet-connected device, are potentially hackable. What if a burglar finds a way to open your smart lock and disable your intelligent security systems? Others worry that products like Nest give Google even deeper reach into our personal data.

One thing is for certain: whether you're set to be an early adopter in the smart home market or you're still on the fence, this is only the beginning for smart homes.

Next big things

Welcome home! Check out some of the features of your oh-so-smart future abode...

Witt induction hobs

www.witt-ltd.com

Induction multizones sunk into the work surface automatically detect where a pan is placed; shut off when a pan is removed, overflows, or boils dry; and offer a pause function if you need to walk away suddenly.

Feed & Go Online Automatic pet feeder

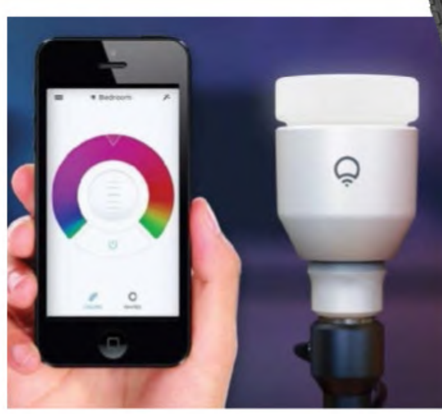
www.feedandgo.com

All the scheduling and dispensing features of a traditional automatic feeder, plus a camera so you can share every gory detail of your pet gobbling up its dinner, and a voice recorder so you can leave it a secret mealtime message.

Lifx LED Bulb

lifx.co

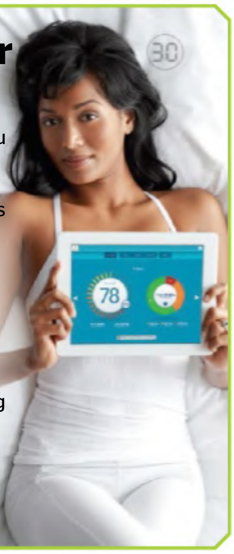
Lets you set endless moods, selecting from over 16 million possible hues in a colour wheel on your smartphone. Can be programmed to brighten and dim slowly at opposite ends of the day, easing you out of and into sleep; to flash when you receive a text or email; and to come on automatically as soon as it detects your smartphone approaching your property. Highly energy efficient, it lasts 27 years.



Nest Protect

nest.com

Combined smoke/carbon monoxide detector gives you a heads up before sounding the full alarm, texts you when its batteries are low, alerts you of hazards detected while you're out and will shut down your Nest Thermostat if it sniffs something untoward.



Sleep Number Sleep IQ

www.sleepnumber.com

Sleep IQ monitors you as you sleep, tracking your heart rate, breathing rate, movements and sleep cycles to calculate the quality of your sleep and help you fine tune details like your bed time, mattress texture and daily habits to attain optimal sleep each and every night. Especially useful if your bedfellow is prone to snoring – Sleep IQ responds to the voice command "Stop snoring!" by gently raising your partner's head while they continue to slumber.

HomeChat by LG

lgusblog.com

With HomeChat you can converse naturally with your appliances to find out what they're up to and make requests. Your fridge might text you to remind you you're running low on milk; you can ask the washing machine, "where are you up to and when will you be done?" You can also set the robot vacuum to work an hour before you return home. They probably won't have any useful relationship advice for you, though.

Belkin WeMo Switch

www.belkin.com

Lets you control any electric appliance remotely from your smartphone. Options to monitor how much energy your devices are consuming, or pair with a motion sensor so that, for example, walking through the front door turns on an appliance in another room.

PointGrab's PointSwitch

www.pointgrab.com

This nifty gadget allows you to control multiple appliances – lights, entertainment systems, air-con and more – from across the room simply by pointing and gesturing, so you won't even need to pick up your smartphone. PointSwitch uses motion-detection algorithms with a standard two-dimensional infrared camera to accurately identify your gesture and its direction. Just remember to turn it off before you start dancing on your own in the lounge…

Elertus Smart Sensor

www.elertus.com

Originally designed to monitor the temperature and humidity of cellars housing prize wines, the Elertus has ballooned into an all-encompassing watchdog that keeps tabs on anything precious to you. As well as clocking temperature and humidity, it will alert you if it detects movement, water, changes in light levels or doors opening and closing.

LED light transmissive carpet

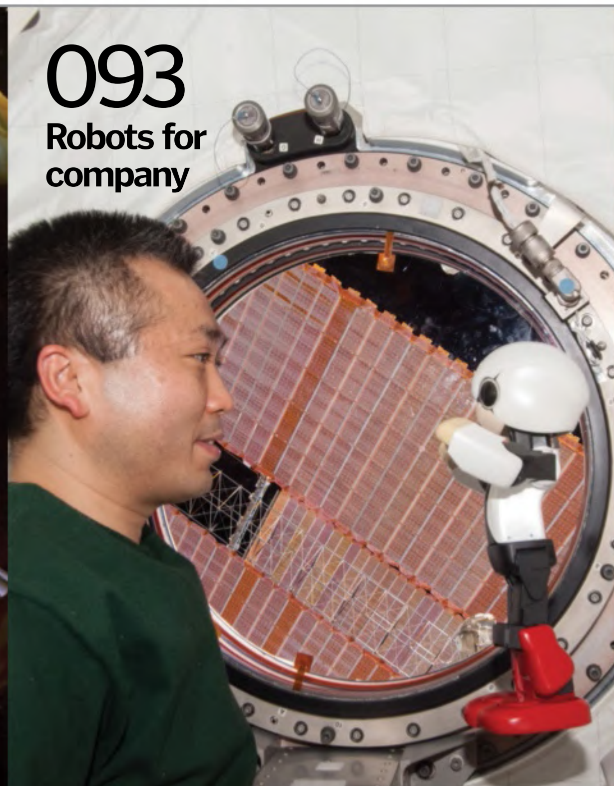
www.philips.com

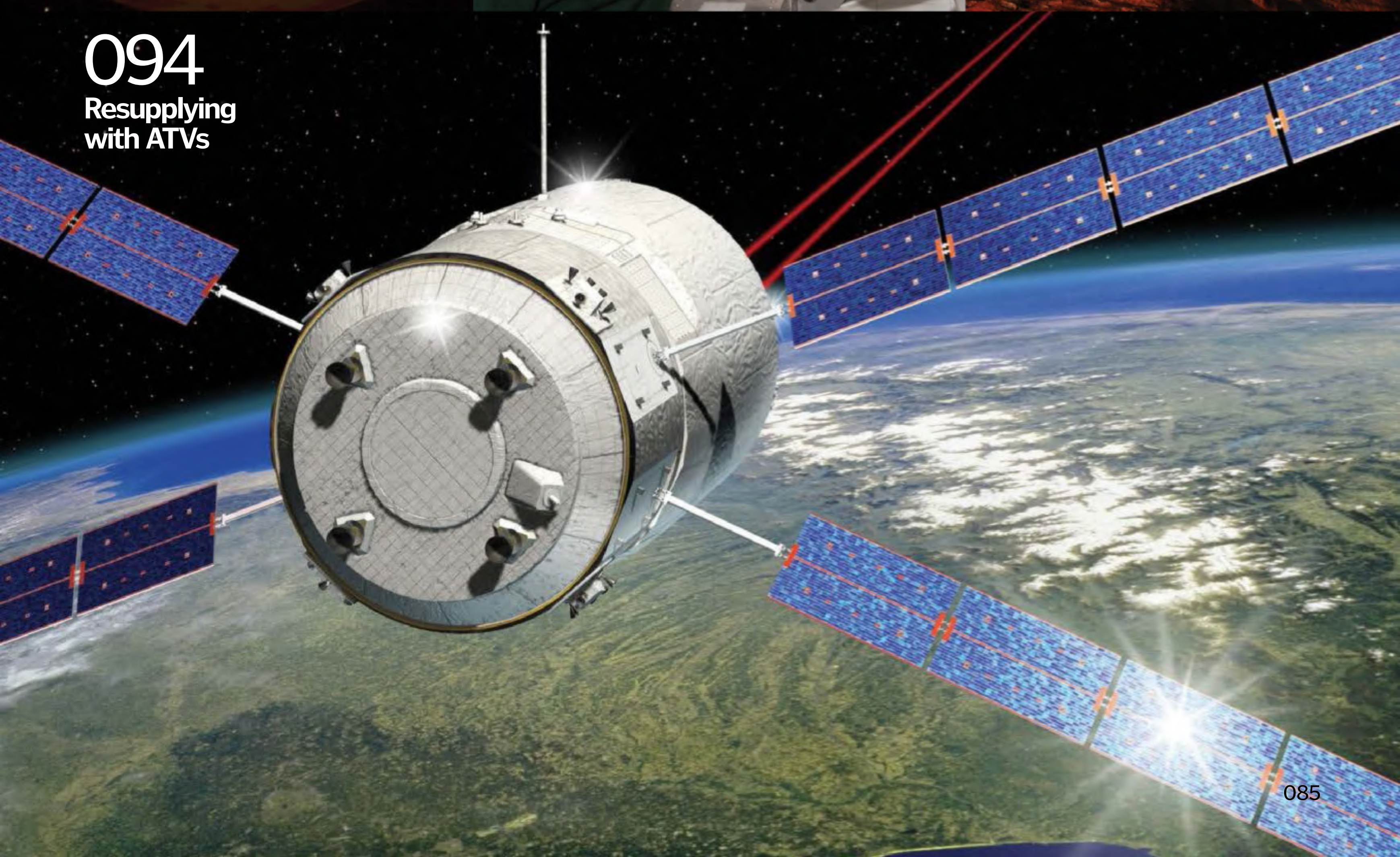
Carpet transmits light from programmable LED arrays laid underneath it. Use it to highlight the route to the bathroom in the night; guide inhabitants to safety during a fire; deliver instructions, directions or greetings to house guests; or – best of all – recreate the music video for *Billie Jean* right there in your living room. Maybe. No, definitely.

SPACE ROBOTS

101
The Mars Hopper

086
Robots in space





Astrobots

Robots have moved from sci-fi to reality with alarming ease. But how is NASA's robotic technology helping us explore the universe?

Use of robotic technology in space goes back much further than Lunokhod 1, the first robot ever to land on a terrestrial body. Even the first unmanned spacecraft (Sputnik) had semi-robotic components on board, although their capabilities were rudimentary at best. However, since the cancellation of the Apollo programme, robots have all but replaced man at the cutting edge of space exploration.

There are several key reasons for this; with cost being top of the list, particularly in today's financial downturn. Robotic missions cost a fraction of their manned equivalents, involve less risk and produce far more useful, empirical information. Just in the last year, India's first unmanned lunar probe, Chandrayaan-1, was found to have detected the probability of ice-filled craters on the moon, something the 12 US astronauts who actually walked on its surface failed to deduce at a cost of tens of billion of dollars. Neil Armstrong's 'one small step for man' may have been symbolic, but the 'great leap for mankind' has since been accomplished by robots. Today, two Mars Exploration Rovers are already hard at work on the surface of a planet man is not expected to reach for at least another decade.

Robotic devices can be found operating in various forms; from satellites, orbiters, landers and rovers to orbiting stations such as Skylab, MIA and the current International Space Station. However, the most impressive of all are the rovers, first used during the Apollo 15 missions in 1971. Devices like rovers still rely on a combination of telemetry and programming to function. However, as the distance they are expected to travel grows, making it harder to receive instructions from Earth, the importance of artificial intelligence in making such devices more autonomous will only grow in future.

Mars Exploration Rovers

NASA's most ambitious strategy since Apollo continues apace with the Mars Exploration Rovers

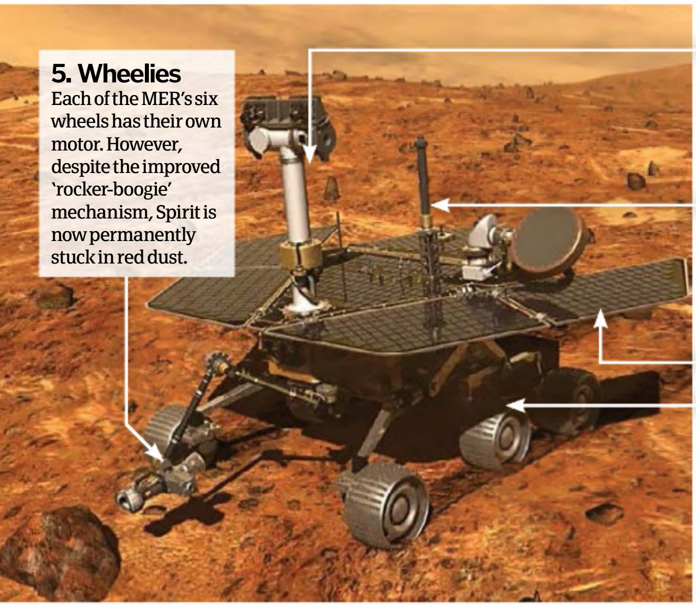
There have been three Mars Exploration Rovers (MER) so far. The first was Sojourner, carried by the groundbreaking Pathfinder, which landed in 1997 and continued to transmit data for 84 days. The second and third (Opportunity and Spirit) touched down three weeks apart in 2004 and are now six years into their missions. Spirit, after a productive start, is now permanently immobile although still functioning. Opportunity is moving steadily across the planet surface, using software to recognise the rocks it encounters, taking multiple images of those that conform to certain pre-programmed characteristics.

DID YOU KNOW? *The US was not first to land an object on Mars. The Russian Mars 2 crash-landed on the surface in 1971*

Mars Exploration Rovers

Spirit and Opportunity are still transmitting from the surface of Mars despite some decidedly archaic components. Although reinforced against radiation, the 32-bit RAD 6000 CPU and 128RAM would sound meagre even in a laptop. However, other aspects are still state of the art, including the aerosol insulated compartment that keeps vital equipment working through the -100° Celsius Martian nights.

NASA engineers work on the Spirit/Opportunity



5. Wheelies
Each of the MER's six wheels has their own motor. However, despite the improved 'rocker-boogie' mechanism, Spirit is now permanently stuck in red dust.

1. Click!
Both MERs boasts a panoramic camera (Pancam) capable of 1024x1024-pixel images that are compressed, stored and transmitted later.

2. Antenna
Spirit and Opportunity use a low-gain antenna and a steerable high-gain antenna to communicate with Earth, the former also used to relay data to the orbiter.

3. Power me up
These MERs boast superior solar technology to Sojourner, with 140 watt solar panels now recharging the lithium-ion battery system for night-time operation.

4. Safeguarding science
A gold-plated Warm Electronics Box protects vital research equipment, including miniature thermal and x-ray spectrometers and a microscopic imager.

The Statistics
Spirit/Opportunity

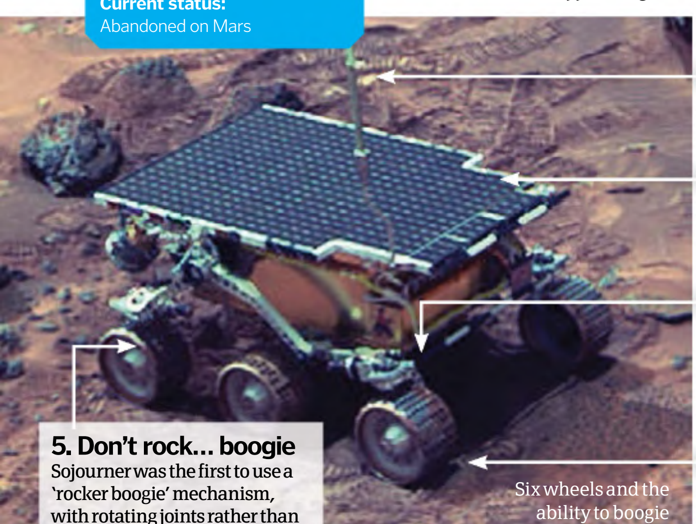
Dimensions: Length: 1.6m, width: 2.3m, height: 1.5m
Mass: 167kg
Top speed: 0.11mph
Mission: Exploration and experimentation
Launch vehicle: Delta II
Lander systems: Guided and parachute
Current status: Active on Mars

Sojourner

The Statistics
Sojourner

Dimensions: Length: 65cm, width: 48cm, height: 28cm
Mass: 10.6kg
Top speed: 0.07mph
Mission: Exploration and experimentation
Launch vehicle: Pathfinder
Lander systems: Soft land and release
Current status: Abandoned on Mars

Sojourner was the first truly self-sufficient rover, largely restoring NASA's space exploration credentials when it touched down on Mars in July 1997. Although it only travelled 100 metres in its 84-day mission, this was 12 times longer than expected, producing a massive amount of data, including over 8.5 million atmospheric measurements and 550 images.



Six wheels and the ability to boogie

1. Telemetry
Sojourner relied on a single high gain antenna to receive instructions from the Pathfinder Lander for the manoeuvres it made.

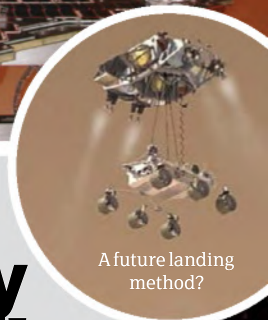
2. Power up
Top-mounted solar cells provided the power. However, the non-rechargeable D-cell batteries led to the mission ending.

3. Payload
A heat-protected box surrounded the rover's key components, including the CPU and an Alpha Proton x-ray spectrometer to analyse the 16 tests performed.

4. Wheels in motion
Sojourner's revolutionary six-wheeled design took the rugged terrain in its stride.

5. Don't rock… boogie
Sojourner was the first to use a 'rocker boogie' mechanism, with rotating joints rather than springs allowing it to tip up to 45 per cent without losing balance.

MSL: To Opportunity and beyond!

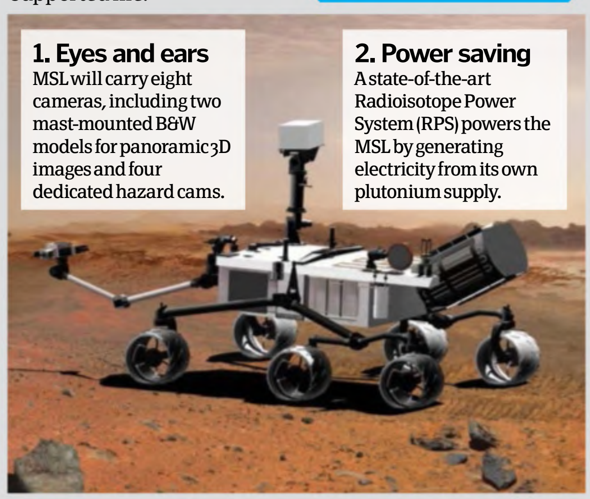


A future landing method?

At a cost of $2.3 billion, the Mars Science Laboratory (MSL) is designed to go much further than the current Opportunity and Spirit MERs. Using four different landing systems it is expected to make a precision landing on Mars in the autumn of 2011. The six-wheeled craft will then spend a year determining whether Mars has ever supported life.

The Statistics
Mars Science Laboratory

Dimensions: Length: 2.7m, width: n/a, height: n/a
Mass: 820kg
Top speed: 0.05mph
Mission: Exploration and experimentation
Launch vehicle: Atlas V 541
Lander systems: Guided, powered, parachute and sky crane
Current status: Testing



1. Eyes and ears
MSL will carry eight cameras, including two mast-mounted B&W models for panoramic 3D images and four dedicated hazard cams.

2. Power saving
A state-of-the-art Radioisotope Power System (RPS) powers the MSL by generating electricity from its own plutonium supply.

3. Ever-increasing circles
Based on the same principle as previous MERs, MSL is far more agile, being able to swerve and turn through 360° on the spot.

4. Intel
MSL's Warm Electronics Box protects vital equipment like the CPU, communications interface and SAM (Sample Analysis at Mars) which literally sniffs the air for gasses.

5. Armed not dangerous
MSL's robotic three-jointed arm can wield five tools, including a spectrometer to measure elements in dust or rocks and a hand lens imager for magnifying samples.

Lunar rovers

Before the MER there was the lunar rover, for a time the most talked-about hand-held technology (not) on Earth

Although lunar rovers seem little more than sophisticated golf-carts compared to today's Mars Rovers, their impact was immense; allowing astronauts and equipment to travel much further than on foot and carry back rock samples that the Apollo 15-17 astronauts later returned to Earth.

The lunar rover was first deployed on Apollo 15 in 1971 and only four were ever built for a cost of $38 million (about $200 million in today's money). Powered by two 36-volt non-rechargeable batteries, the rovers had a top speed of eight miles per hour, although astronaut Gene Cernan still holds the lunar land speed record of an impressive 11.2mph. All three rovers remained on the lunar surface after their mission ended.

The Statistics

Lunokhod 2

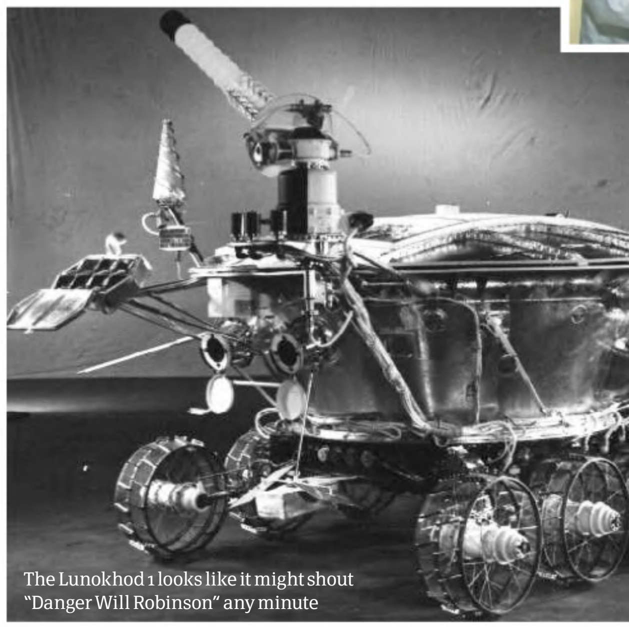
Dimensions: Length: 170cm, width: 160cm, height: 135cm
Mass: 840kg
Top speed: 1.2mph
Mission: Exploration and experimentation
Launch vehicle: Luna 17
Lander systems: n/a
Current status: Abandoned on moon

Lunokhod One and Two

Apollo may have put Armstrong on the moon, but for robotics, Lunokhod was the benchmark

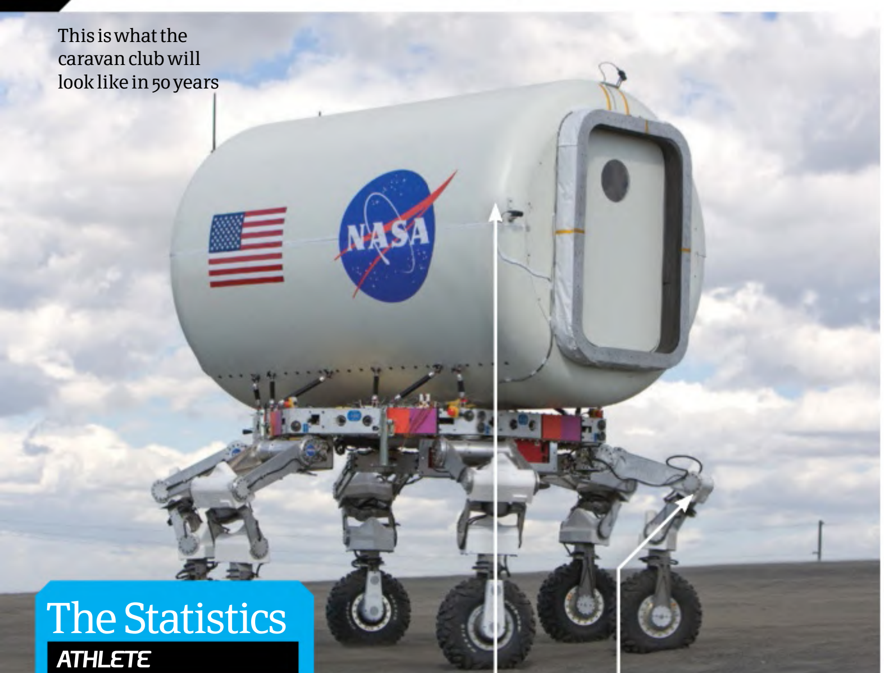
Lunokhod 1 was the first unmanned vehicle ever to land on a celestial body in 1970. The Russian designed and operated rover packed a lot into its 2.3 metre length, including four TV cameras, extendable probes for testing soil samples, an x-ray spectrometer, cosmic ray detector and even a simple laser device. It was powered by solar rechargeable batteries and equipped with a cone-shaped antenna to receive telemetry. It exceeded its mission time by lasting nearly 322 days, performing soil tests, travelling over 10.5 kilometres and returning over 20,000 images.

Lunokhod 2 followed in 1973, an eight-wheeled solar powered vehicle equipped with three TV cameras, a soil mechanics tester, solar x-ray experiment, an astrophotometer for measuring visible and ultraviolet light levels, a magnetometer, radiometer, and a laser photodetector. Its mission lasted only four months before Lunokhod 2 overheated, however in this time it covered 37km and sent back over 80,000 pictures.



The Lunokhod 1 looks like it might shout "Danger Will Robinson" any minute

This is what the caravan club will look like in 50 years



Payload
Large payload capacity of 450kg per vehicle, with much more for multiple ATHLETE vehicles docked together.

Legs
R6-DOF legs for generalised robotic manipulation base can climb slopes of 35° on rock and 25° on soft sand.

Walk
Capable of rolling over Apollo-like undulating terrain and 'walking' over extremely rough or steep terrain.

The Statistics

ATHLETE

Dimensions: Diameter: 4m
Mass: Unknown
Top speed: 6.5mph
Mission: Transport, exploration and experimentation
Launch vehicle: TBC
Lander systems: n/a
Current status: In development

Introducing the ATHLETE

The competition for future robots in space is fierce, with commercial companies developing contenders like ATHLETE

Currently under development by the Jet Propulsion Laboratory (JPL), the All-Terrain Hex-Legged Extra-Terrestrial Explorer (ATHLETE) is designed to be the next generation of MERs; bigger, faster and more versatile than the current models.

It's also the most striking to look at, about the same size as a small car with a spider-like design incorporating a central base and six extendable legs, mounted on wheels, allowing it to travel over a wide variety of terrains.

Future plans include the addition of a voice or gesture interface for astronaut control and a grappling hook to haul it up vertical slopes. ATHLETE's modular design allows it to dock with other equipment, including refuelling stations and excavation implements. It also boasts a 450kg payload capability, making it a powerful workhorse.

The big cloud over ATHLETE is the current recession which is now placing the whole 'Human Lunar Return' strategy, for which it was designed, in jeopardy.

SPAR Aerospace Ltd, a Canadian company, designed, developed, tested and built the Canadarm

The Canadarm Remote Manipulator System

It will never win awards for its looks but the Canadarm has worked harder than any space robot before

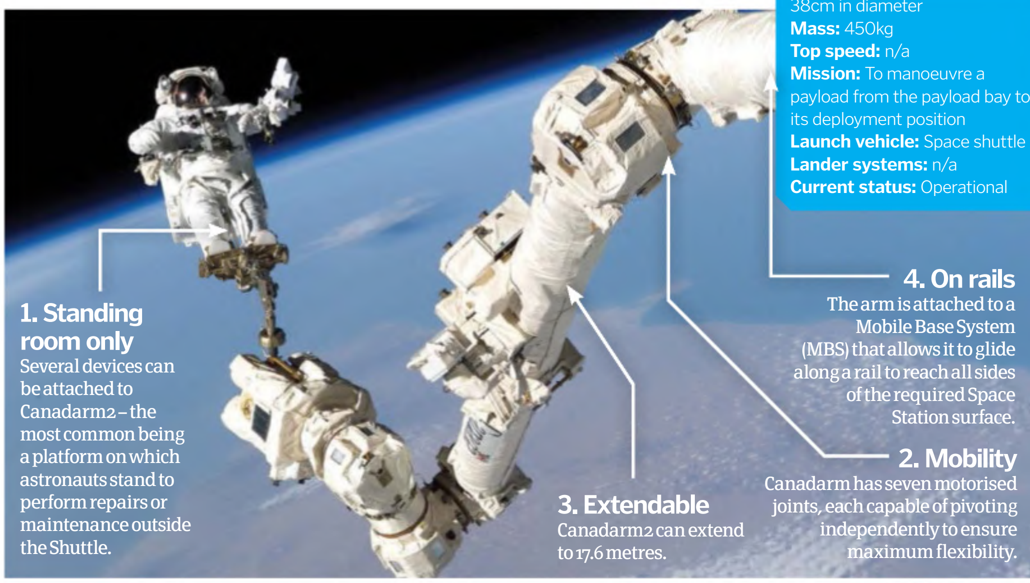
Remote manipulator systems (RMS) have been around since the Fifties, but it wasn't until 1975 that one achieved its own nickname. The Canadarm became both a symbol of national engineering pride for the country that designed and built it (Canada) and the most recognisable and multi-purpose tool on the Space Shuttle.

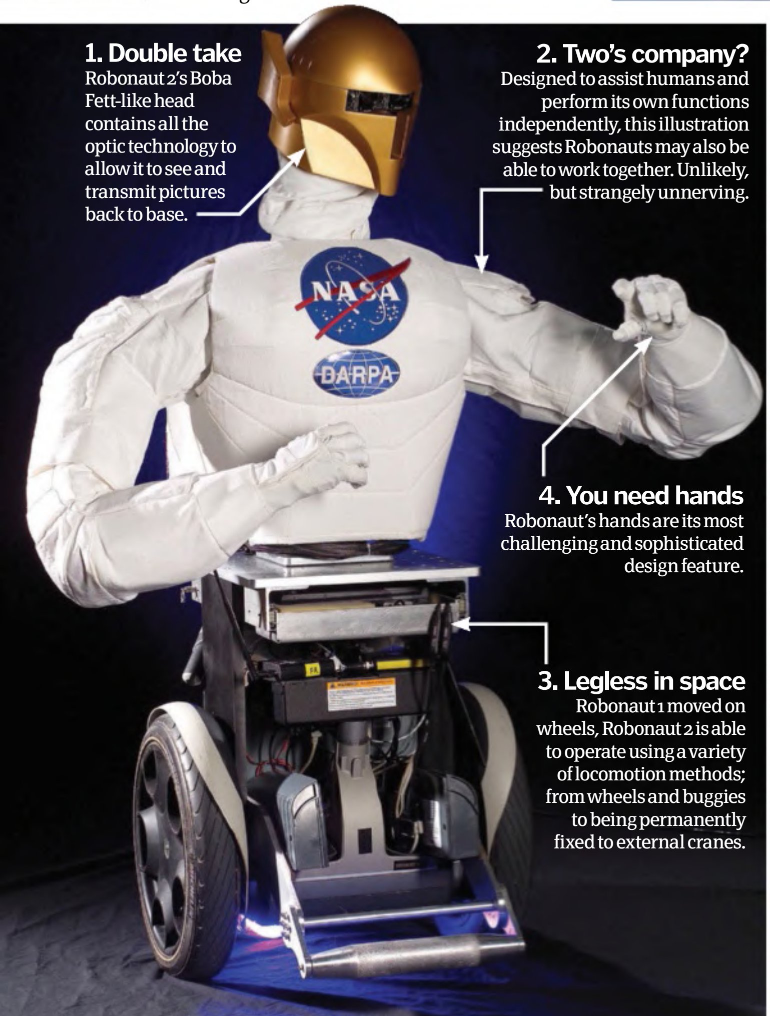
The Shuttle Remote Manipulator System (to give it its real name) is a 50-foot arm capable of lifting loads, manipulating them at small but precise speeds. It has been used extensively in Shuttle missions for a variety of purposes including ferrying supplies, dislodging ice from the fuselage and performing crucial repairs to the Hubble Space Telescope. Canadarm has never failed. Its successor, Canadarm2, is a key part of the ISS, used to move massive loads of up to 116,000kg. It is also useful in supporting astronauts on EVAs and servicing instruments.

The Statistics

Canadarm

Dimensions: 15.2m long and 38cm in diameter
Mass: 450kg
Top speed: n/a
Mission: To manoeuvre a payload from the payload bay to its deployment position
Launch vehicle: Space shuttle
Lander systems: n/a
Current status: Operational





Humanoid robots

Will we ever see a robot with real human abilities?

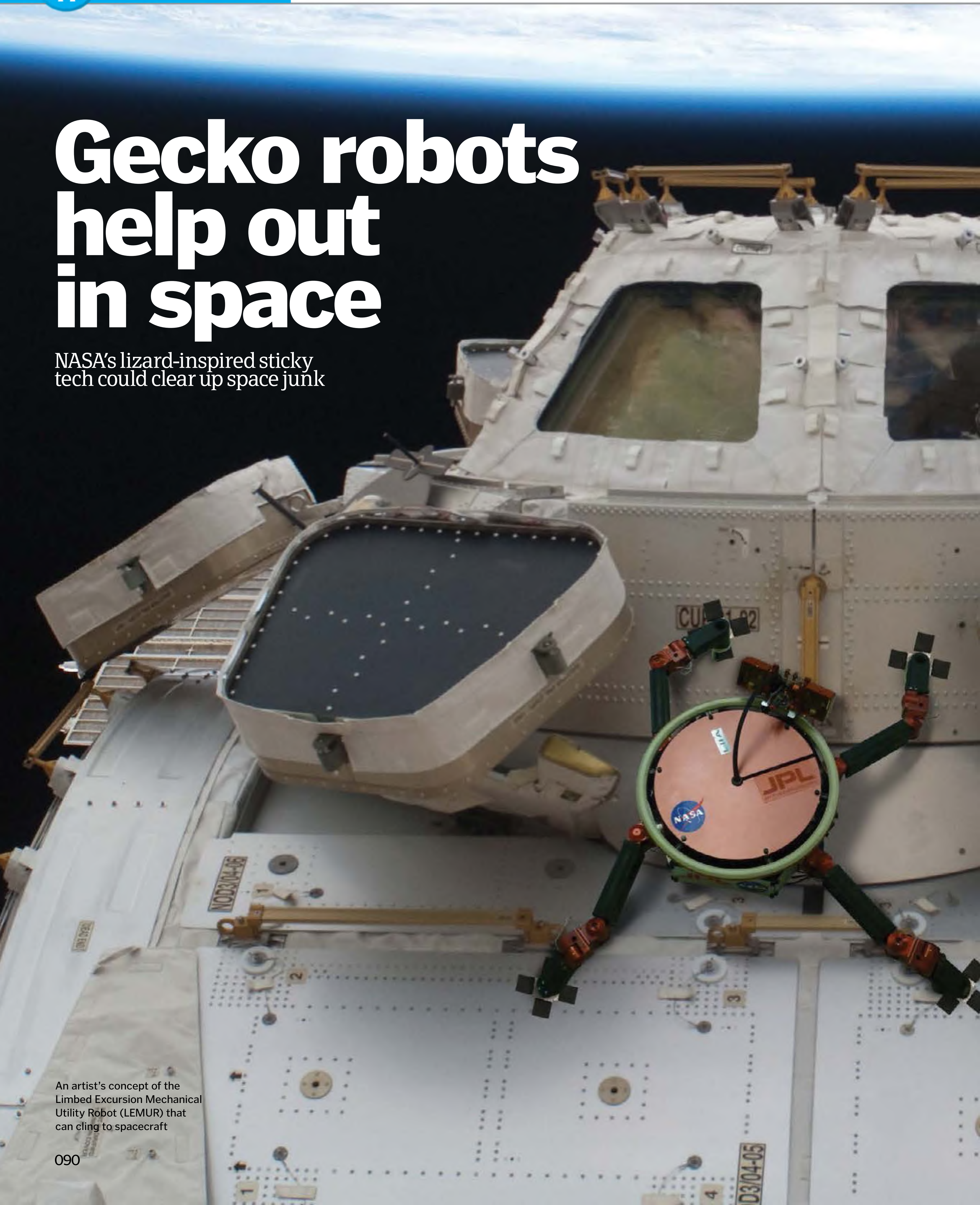
When the original Robonaut was unveiled at the Johnson Space Center (JSC) nearly a decade ago, one glance at its Davros-like design revealed the glaring weakness. How could something on a fixed-wheel chassis really help in the demanding EVAs for which it was required? The answer, currently under development by JSC and General Motors, is called Robonaut 2.

Robonaut 2 adds advanced sensor and vision technologies to do far more than basic lifting and moving, as currently performed by devices like the Canadarm. Whether helping with future repairs at the ISS, maintaining base stations for planetary landings, or doing hazardous jobs in the motor and aviation industries, Robonaut 2 is designed to work anywhere using bolt-on arm and leg appendages appropriate to the task at hand.

While not as dextrous as a real human hand, Robonaut 2's hands have 14 degrees of freedom and contain touch sensors at the fingertips

Gecko robots help out in space

NASA's lizard-inspired sticky tech could clear up space junk



An artist's concept of the Limbed Excursion Mechanical Utility Robot (LEMUR) that can cling to spacecraft

In space, Velcro is currently the sticking method of choice, with astronauts using it to secure equipment to the interior walls of the International Space Station in microgravity. However, Velcro has the drawback of needing a suitable surface to stick to, so NASA has now turned to nature to help them find a better alternative.

Its engineers have developed a material inspired by gecko feet that can cling to almost any surface, doesn't leave any residue and won't lose its stickiness over time. The gecko-grippers even work in extreme temperature, pressure and radiation conditions, so the vacuum of space won't be an issue. The adhesive uses tiny synthetic hairs, thinner than a human's, that create van der Waals forces when weight is applied – the same technique used by geckos.

The adhesive has already been tested on a microgravity flight, proving that it can hold the weight of a 100-kilogram (220-pound) human. It is now being used to develop a climbing robot with sticky feet that could be used to inspect and repair the exterior of the ISS. NASA even hopes that this technology could one day be used to grab space junk and clear it from orbit.

A gecko's sticky feet

Geckos are one of nature's greatest climbers, as they can stick to almost any surface and even cling to ceilings. The secret of their stickiness comes down to the millions of tiny hairs on their feet and some clever physics. Each of the microscopic hairs contain molecules with positively and negatively charged parts, and when these molecules come into contact with another surface, they are attracted to the opposite charges in that surface, forming van der Waals forces. This is then strengthened when the gecko bears its weight down to bend the hairs, so it can unstick itself by straightening them again.

Future space tech on Titan

The autonomous technology that NASA hopes will solve many of Titan's mysteries

The Titan Aerial Daughtercraft has been put forward by the NASA Innovative Advanced Concepts (NIAC) programme with the aim of sending a small quadcopter drone to Titan, alongside a mothership. The drone would operate above the moon's surface, landing to take samples when required. When the drone's charge runs out, it would be able to return to the mothership, where it could recharge and then continue its mission.

Unlike the Mars rovers, the drone would be designed to work autonomously. It would be left to gather research for days at a time, before returning its data to Earth via the mothership. As it stands there is no set date for such a mission to Titan, however the interest that has been sparked by the Huygens probe will no doubt encourage this mission to materialise.

View of Saturn
From the side of Titan's surface that constantly faces the ringed planet, Saturn would just be visible through the thick hazy atmosphere.

Drone charging
When low on power, the drone could automatically return to the mothership to recharge, before starting another set of samples.

Drone flight
The drone is likely to weigh less than ten kilograms (22 pounds), and will be capable of taking high-resolution pictures while it collects samples.

Surface samples
One of the drone's primary objectives would be to collect surface samples, including soil and liquid.

Scientific instruments
The submarine will be equipped with an array of scientific instruments, allowing it to examine the chemical composition of Titan's seas, and to check for signs of life.

Intelligent design
Although the final design is still to be confirmed, the submarine is likely to have a light, enabling it to see clearly underwater.

Submarine mission

The Kraken Mare is the largest known sea on Titan. Scientists are interested in exploring this giant liquid mass, which is over 1,000 kilometres (621 miles) wide, and is thought to be roughly 300 metres (984 feet) deep. The NIAC has proposed an autonomous submarine, which could search the hydrocarbon seas while a drone scans the land above. The primary aim would be to study the sea's liquid composition closely, to find out exactly what it is made of. Furthermore, the submarine would search for signs of plant or microbial life, which could be lurking deep beneath the liquid's surface. This data would then be transmitted back to Earth via a mothership once the submarine returned to the surface.

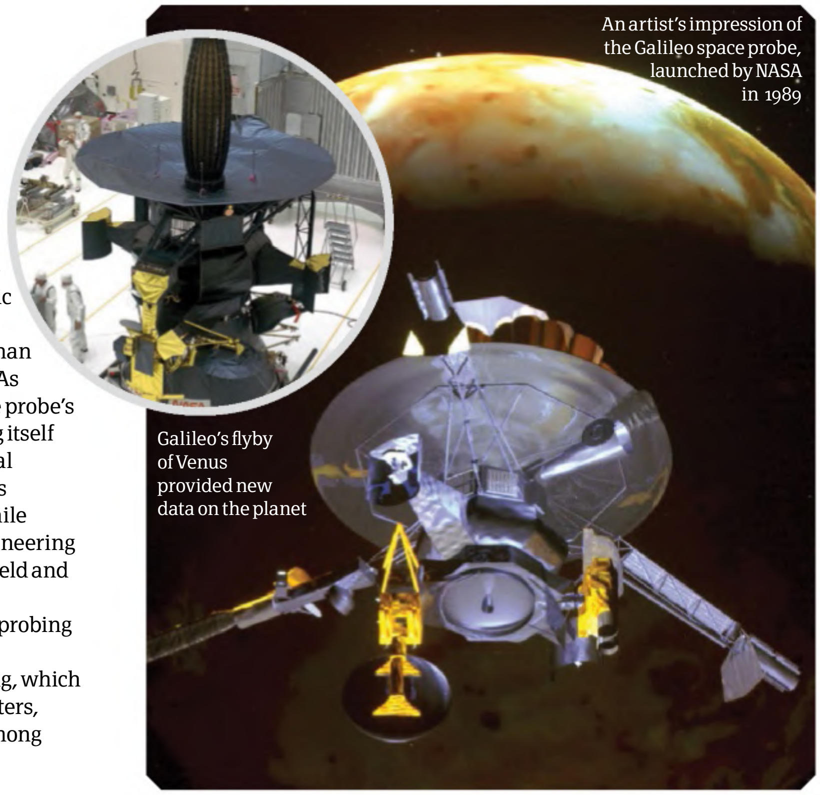
Unmanned space probes

They have made some of the most fundamental discoveries in modern science, but how do space probes work?

On 4 October 1957 the former Soviet Union launched the world's first successful space probe, Sputnik 1, heralding the start of the space race between Russia and the USA. In the initial ten years the vast majority of man's efforts to conduct scientific experiments in space were failures, and it wasn't until the late Sixties that successes were achieved. While many were chalked up to launch failures, most couldn't weather the harsh realities of space.

Withstanding temperature extremes is a monumental task in itself. Of course, it's not temperatures that pose problems for probes wanting to land in alien environments, they must also be capable of putting up with intense radiation and atmospheric pressures which fluctuate from pure vacuum to 90 times that of Earth's surface pressure and beyond. Russia's 1970 Venera 7 probe successfully landed on the surface of Venus and managed to send data back for just 23 minutes before being crushed under the immense pressure exuded on it.

Not only do space probes have to act as highly sensitive scientific instruments, but they have to be built tougher and more rugged than the hardiest black box recorder. As such, the vast majority of a space probe's design is dedicated to sustaining itself and protecting its mission-critical systems. Ultimately their makers consider four fields of science while they're under construction. Engineering (ultimately self sustainability), field and particle sensing (for measuring magnetics among other things), probing (for specific 'hands-on' scientific experiments) and remote sensing, which is usually made up of spectrometers, imaging devices and infrared among other things.



An artist's impression of the Galileo space probe, launched by NASA in 1989

Galileo's flyby of Venus provided new data on the planet

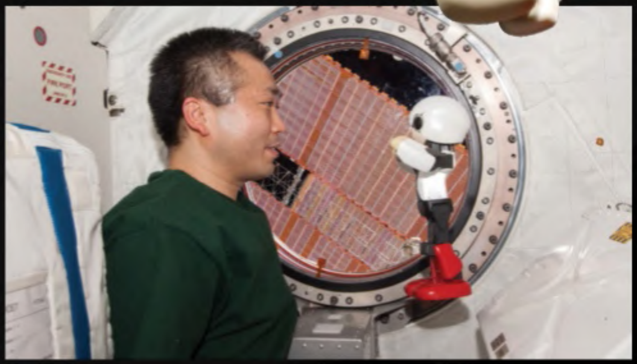
How robots keep astronauts company

Meet Kirobo, the Japanese robot living on the ISS

Feelings of loneliness are often hard to avoid when you're in space. Astronauts who stay on the International Space Station (ISS) for extended periods often struggle with this. Sometimes, their psychological issues can be harder to deal with than living in microgravity or sleeping upright.

To combat this, Japanese scientists designed a robot with the aim of providing psychological support. It was named Kirobo, which is derived from the Japanese word for hope ("kibo") and robot. Kirobo stands 34 centimetres (13.4 inches) tall and weighs one kilogram (2.2 pounds). It has a clever voice-recognition system and can produce its own sentences with the help of an advanced language-processing system, and its own built-in voice synthesis software.

These innovative systems were actually designed by Toyota, which plans to use the technology to develop other robots' conversational abilities. The Kirobo experiment also aimed to see how humans and robots might live alongside each other during longer space missions, which may take place in the future. Kirobo has now returned to Earth after an 18-month stay aboard the ISS.



Automated transfer vehicles

How do these European resupply craft keep the ISS fully stocked?


Each ATV is capable of carrying 6.6 tons of cargo to the ISS

The European Space Agency's (ESA) automated transfer vehicles (ATVs) are unmanned spacecraft designed to take cargo and supplies to the International Space Station (ISS), before detaching and burning up in Earth's atmosphere. They are imperative in maintaining a human presence on the ISS, bringing various life essentials to the crew such as water, food and oxygen, in addition to bringing along some new equipment and tools for conducting experiments and general maintenance of the station.

The first ATV to fly was the Jules Verne ATV-1 in 2008; it was named after the famous 19th-century French author who wrote *Around The World In 80 Days*. This was followed by the (astronomer) Johannes Kepler ATV-2 in February 2011, and will be succeeded by the (physicists) Edoardo Amaldi and Albert Einstein ATVs in 2012 and 2013, respectively. The ATV-1 mission differed somewhat from thesubsequent ones as it was the first of its kind attempted by the ESA and thus various additional procedures were carried out, such as testing the vehicle's ability to manoeuvre in close proximity to the ISS for several days to prevent it damaging the station when docking. However, for the most part, all ATV missions are and will be the same.

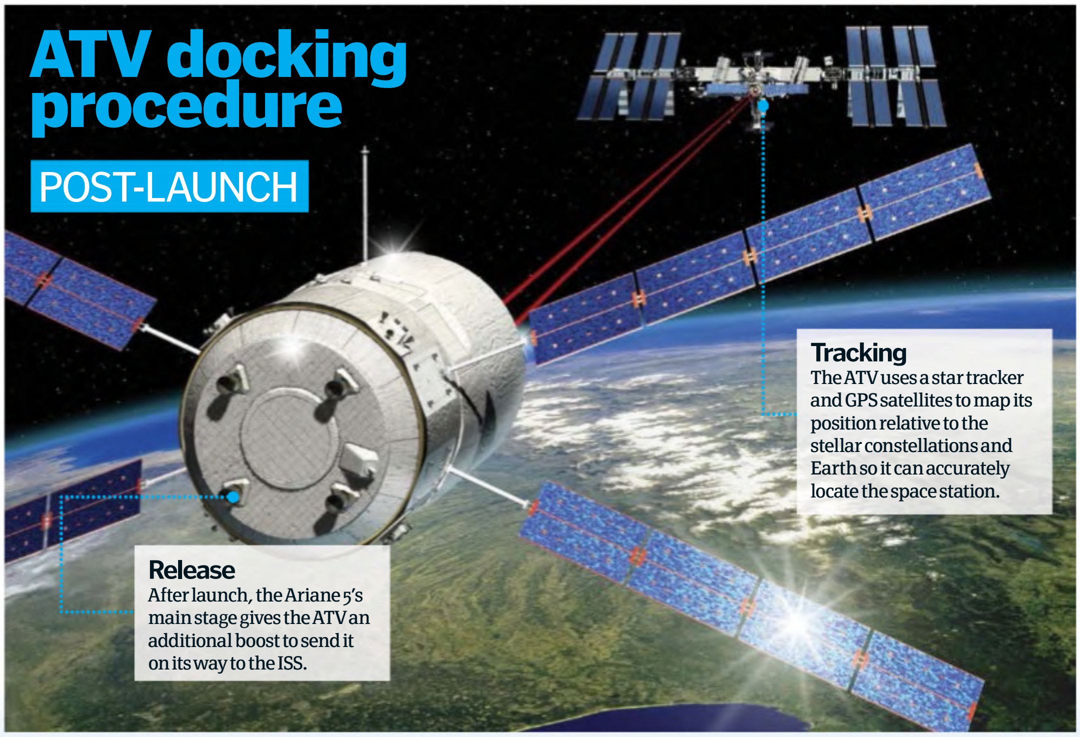
ATVs are launched into space atop the ESA's Ariane 5 heavy-lift rocket. Just over an hour after launch the rocket points the ATV in the direction of the ISS and gives it a boost to send it on its way, with journey time to the station after separation from the rocket taking about ten days.

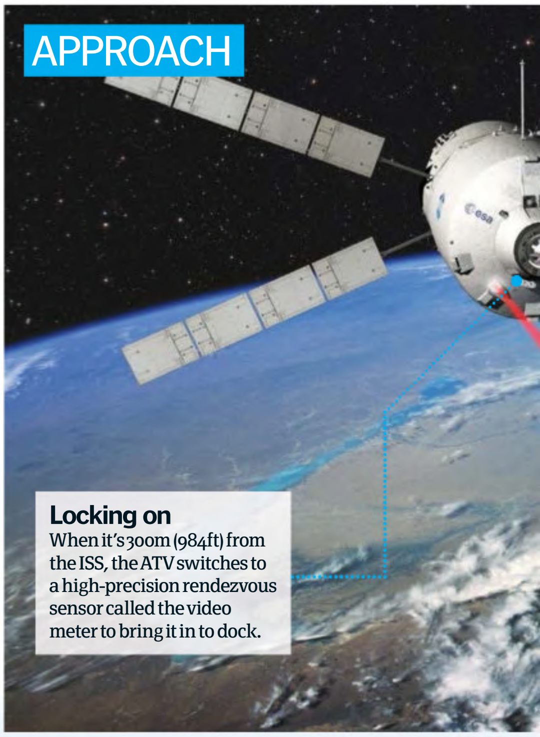
The ATV is multifunctional, meaning that it is a fully automatic vehicle that also possesses the necessary human safety requirements to be boarded by astronauts when attached to the ISS. Approximately 60 per cent of the entire volume of the ATV is made up of the integrated cargo carrier (ICC). This attaches to the service module, which propels and manoeuvres the vehicle. The ICC can transport 6.6 tons of dry and fluid cargo to the ISS, the former being pieces of equipment and personal effects and the latter being refuelling propellant and water for the station.

As well as taking supplies, ATVs also push the ISS into a higher orbit, as over time it is pulled towards Earth by atmospheric drag. To raise the ISS, an ATV uses about four tons of its own fuel over 10-45 days to slowly nudge the station higher.

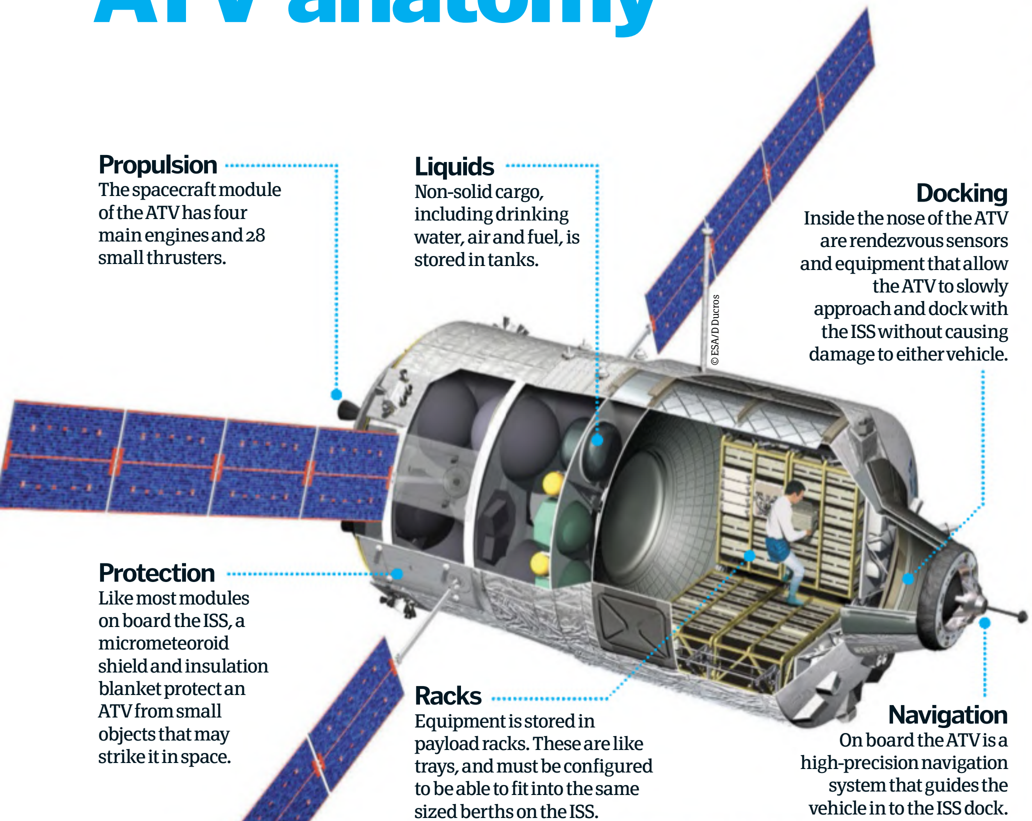
The final role of an ATV is to act as a waste-disposal unit. When all the useful cargo has been taken from the vehicle, it is filled up with superfluous matter from the ISS until absolutely no more can be squeezed in. At this point the ATV undocks from the station and is sent to burn up in the atmosphere.

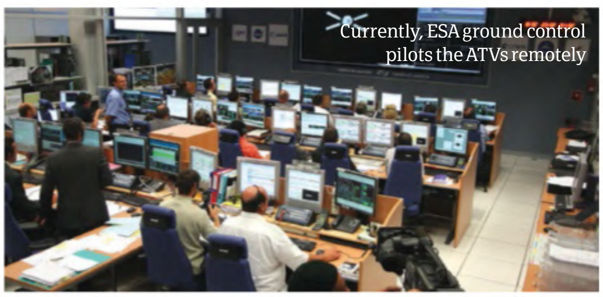
ATV docking procedure





ATV anatomy




Currently, ESA ground control pilots the ATVs remotely

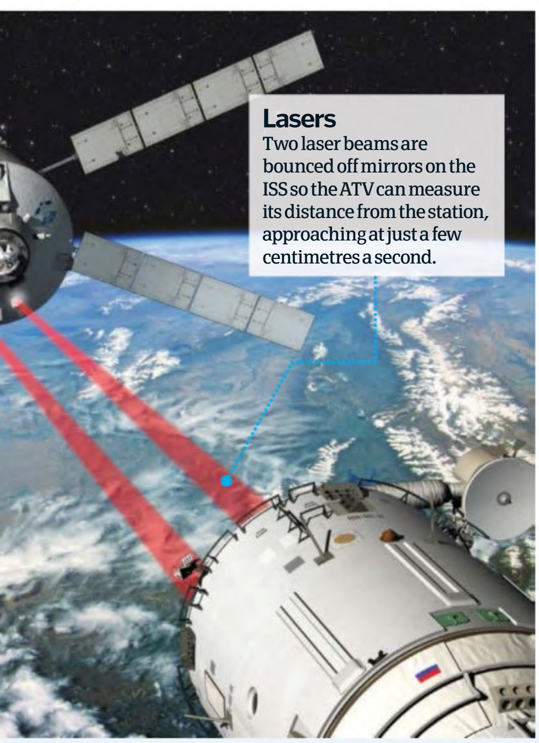

The MPLM was transported inside NASA's Space Shuttle

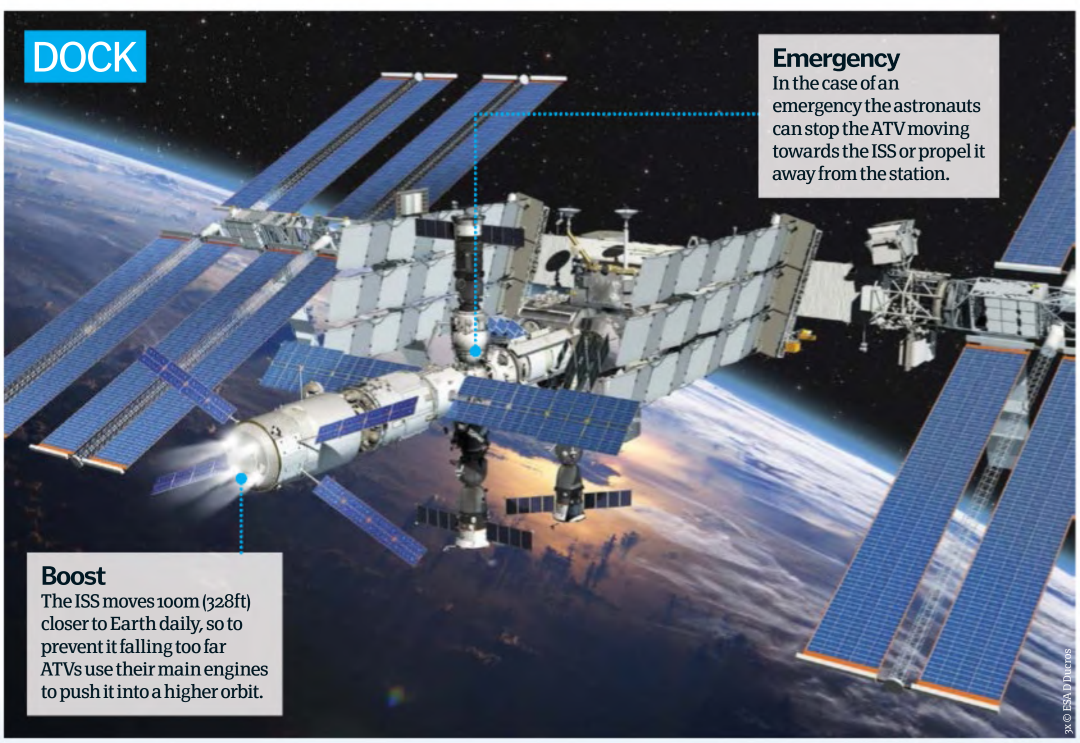
Other resupply vehicles

The ESA's automated transfer vehicle isn't the only spacecraft capable of taking supplies to the ISS. Since its launch, three other classes of spacecraft have been used to take cargo the 400 kilometres (250 miles) above Earth's surface to the station. The longest serving of these is Russia's Progress supply ship, which between 1978 and the present day has completed over 100 missions to Russia's Salyut 6, Salyut 7 and Mir space stations, as well as the ISS.

Succeeding Progress was the Italian-built multipurpose logistics module (MPLM), which was actually flown inside NASA's Space Shuttle and removed once the shuttle was docked to the space station. MPLMs were flown 12 times to the ISS, but one notable difference with the ATV is that they were brought back to Earth inside the Space Shuttle on every mission. The ATV and MPLM share some similarities, though, such as the pressurised cargo section, which is near identical on both vehicles.

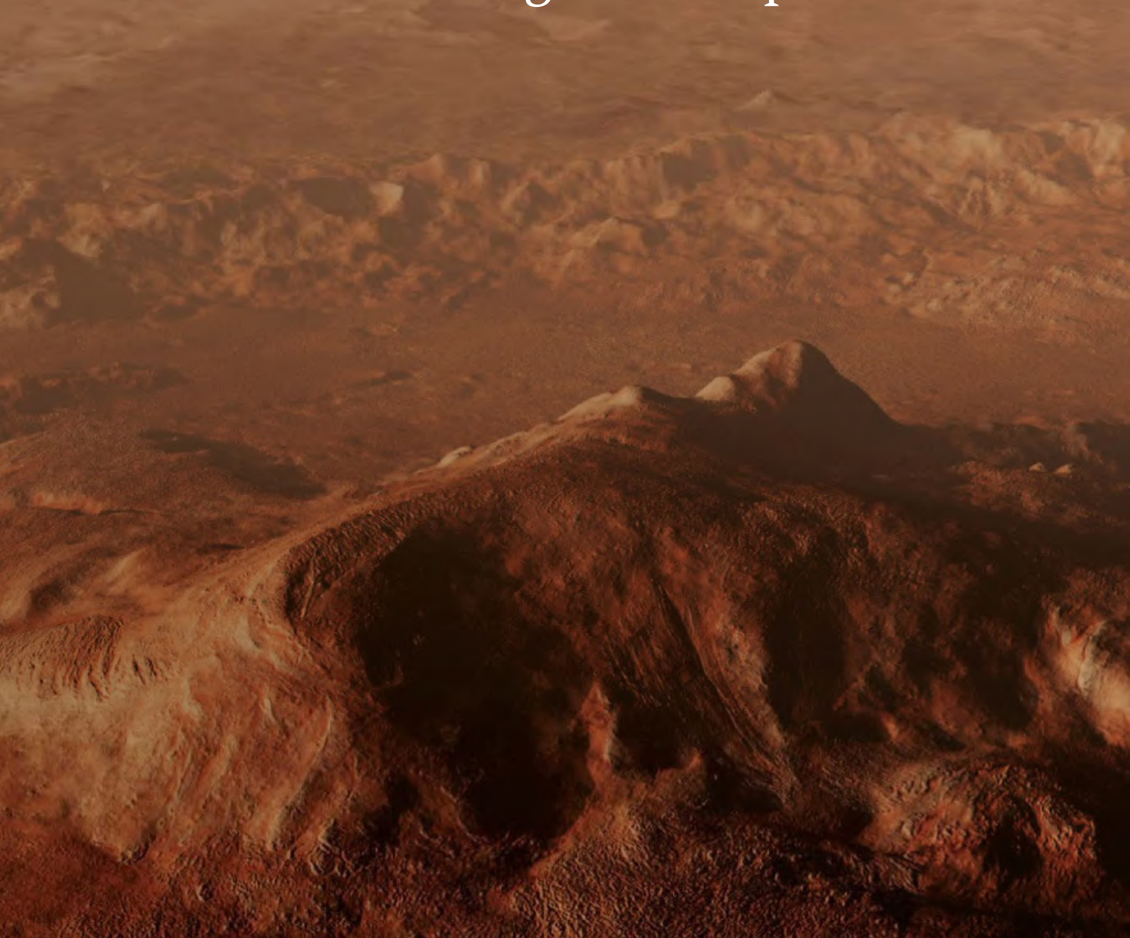
The last and most recent resupply vehicle is the Japanese H-II transfer vehicle (HTV). It has completed one docking mission with the ISS to date, in late 2009, during which it spent 30 days attached to the station.





EXPLORING NEW WORLDS

Going where no one has gone before, these robotic rovers are our eyes and hands which we can use to investigate alien planets



Crawling, trundling and perhaps one day walking across the surface of other worlds, roving vehicles are designed to cope with the roughest terrain and most hostile conditions the Solar System has to offer. The famous Lunar Roving Vehicle (LRV) driven by NASA astronauts on the later Apollo missions is a distant cousin of the robot explorers that have been revealing the secrets of Mars since the late-Nineties, and may one day venture to even more distant planets and their satellites. Equipped with ever-more sophisticated instruments, they offer a cheaper and safer – if less versatile – alternative to human exploration of other worlds.

While the LRV is probably the most famous wheeled vehicle to have travelled on another body, the true ancestors of modern robot missions were the Soviet Lunokhod rovers. Resembling a bathtub on wheels with a tilting 'lid' of solar panels, two Lunokhods operated for several months on the Moon in the early-Seventies. Despite this success, however, it was 1997 before another rover – NASA's small but robust Sojourner, landed on the surface of Mars. Sojourner's success paved the way for the larger and more ambitious Mars Exploration Rovers, Spirit and Opportunity, then even more successful Curiosity, and planned missions such as the ESA's ExoMars rover, due in 2018.

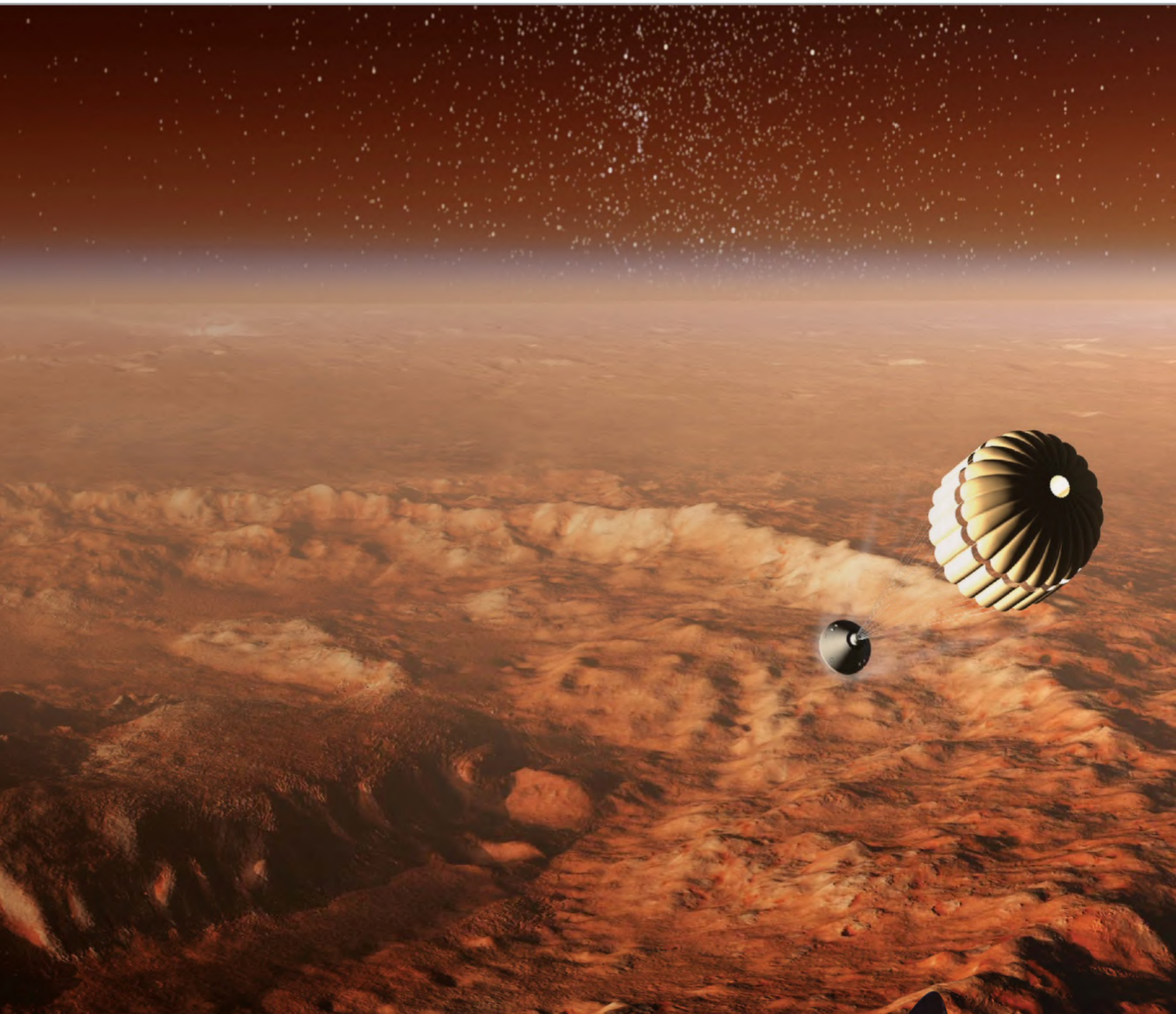
Robotic rovers have to cope with a huge range of challenges; millions of miles from any human assistance, they need to tackle the roughest terrain without breaking down or tipping over. Designs such as the car-sized Curiosity run on a set of robust wheels, each with an independent drive motor and suspension so that if one does become stuck the others carry on working. In order to see how their designs will manage in alien conditions, engineers first test them in hostile Earth environments such as California's Mojave Desert near Death Valley. Engineering teams on Earth even maintain a 'clone' of their Martian rovers so they can test difficult manoeuvres in safe conditions on Earth prior to the real thing.

These robot explorers carry a variety of equipment, often including weather stations, an array of cameras, robotic arms, sampling tools and equipment for chemical analysis. Science teams on Earth study images of the rover's surroundings and decide on specific targets for study, but the rover often conducts many of its basic operations autonomously.

What rovers lack in flexibility compared to human astronauts, they make up for in endurance. Drawing power from solar panels or the heat from radioactive isotopes, they can operate for months or even years (indeed, NASA's Opportunity rover landed in the Meridiani Planum region in January 2004 and is still running more than nine years later).

Properly designed, they can resist the dangers of high-energy radiation and extreme temperature changes and, of course, they don't need food, drink or air to breathe. In the future, designs for multi-legged 'walking' rovers may make our mechanical stand-ins even more flexible, helping to further bridge the gap between robotic and human explorers.

DID YOU KNOW? *Spirit and Opportunity owe their long lives to Martian winds blowing away dust from their solar panels*



Keeping in touch with Earth

Sending commands to a rover in space is a unique challenge. While radio signals take little more than a second to reach the Moon, signals can take anything from four to 21 minutes to reach a robot on the Red Planet.

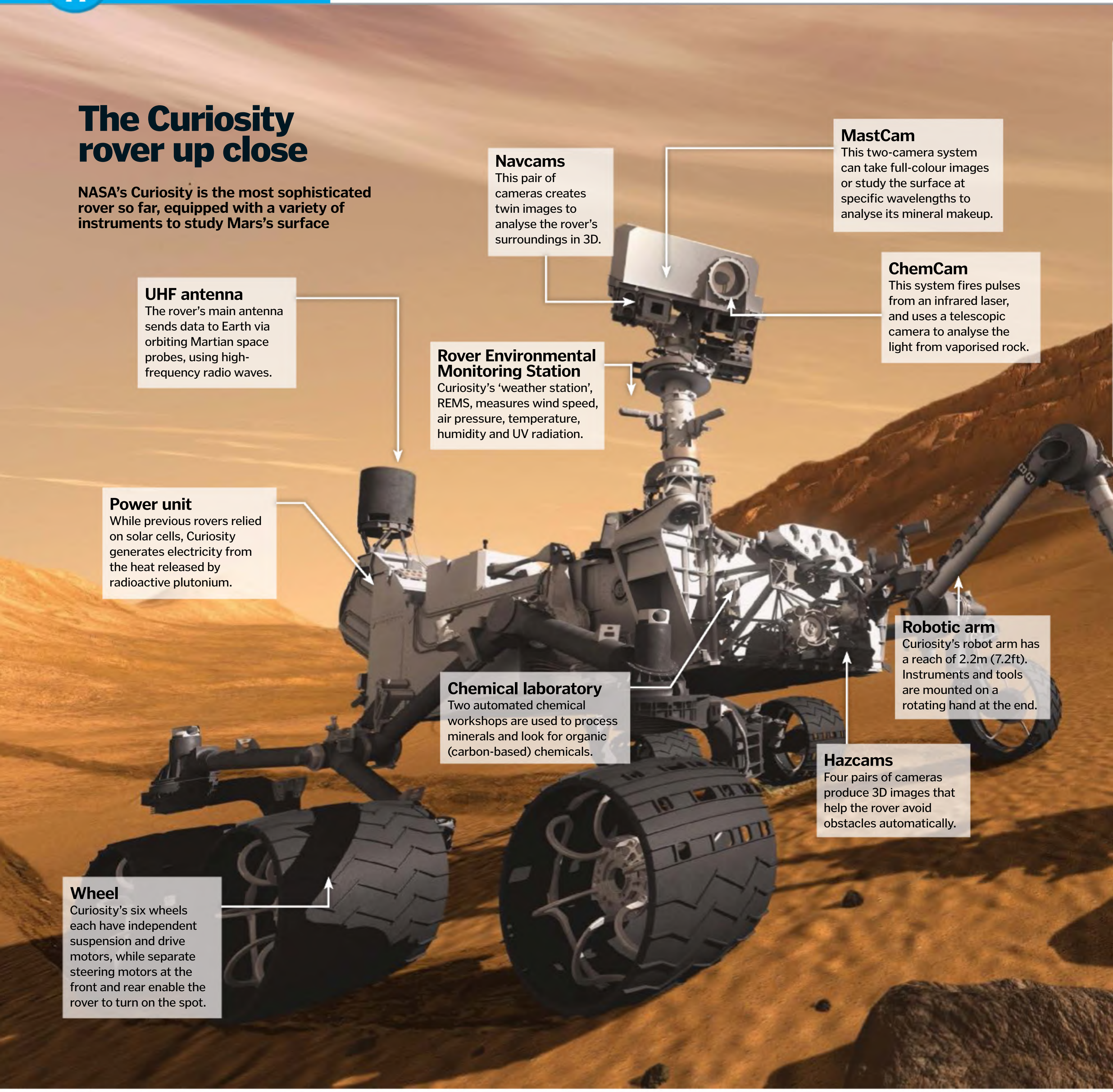
So while the first Soviet Moon rovers could be 'remote controlled' with just a little delay, it's impossible to do the same with Martian rovers; it would simply take too long to send each command and assess its results.

Instead, rovers from Sojourner through to Curiosity and beyond are pre-programmed with a range of functions that allow them to work more or less independently; their operators back on Earth select directions of travel and rocks for inspection, and the rover can then do many of the tasks for itself.

The huge distance to Mars also causes problems for the strength of radio signals, since it's impractical for a rover to carry a directional high-gain antenna dish and keep it locked on to Earth. Instead, rovers use broadcast radio antennas to send their signals to a relay station (usually a Mars-orbiting satellite), which then uses its dish antenna to relay them to Earth. In case of emergencies, however, modern rovers are also usually capable of slow communications directly with Earth.

The Curiosity rover up close

NASA's Curiosity is the most sophisticated rover so far, equipped with a variety of instruments to study Mars's surface



Roving through history

We pick out some of the major milestones in the development of rovers

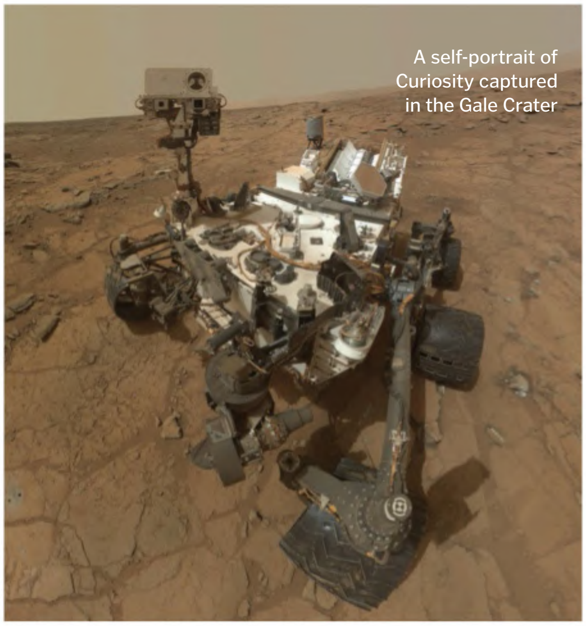
1970
The Soviet Union's Lunokhod 1 lands on the Moon. The first-ever off-Earth rover operates for ten months.

1971
NASA's Apollo 15 mission lands the first of three Lunar Roving Vehicles on the surface of the Moon.

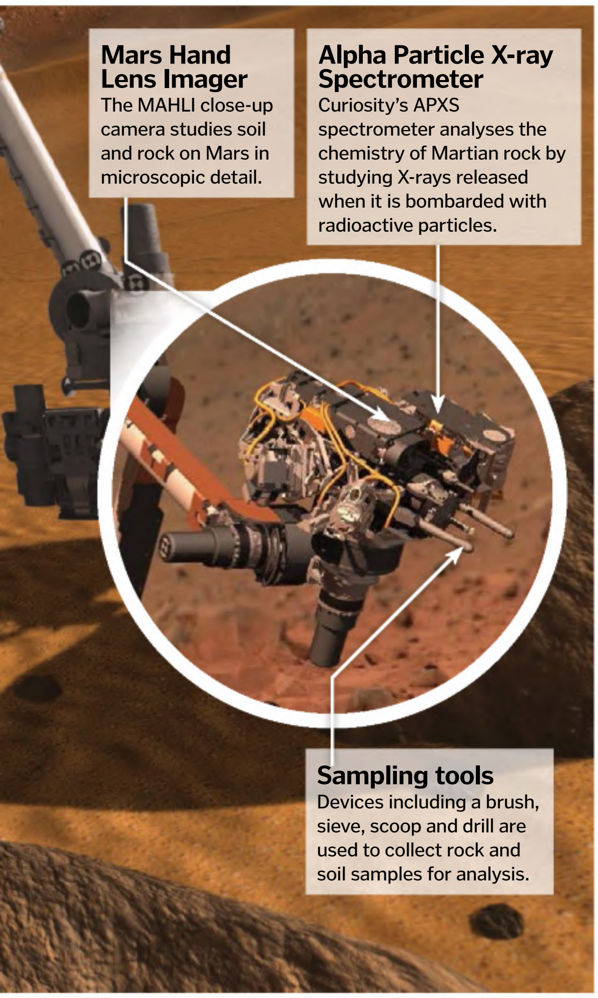
1973
Lunokhod 2 lands on the Moon, operating for four months but failing when it overheated, presumably due to soil contamination.

1997
NASA's Mars Pathfinder mission carries the Sojourner, a small robot that becomes the first rover on another planet.

2004
NASA's Mars Exploration Rovers, Spirit and Opportunity, land on opposite sides of the planet in the Gusev Crater and Meridiani Planum, respectively.



A self-portrait of Curiosity captured in the Gale Crater



On-board technology

Rovers can carry a variety of different equipment for studying the soil of other worlds. Multispectral cameras (capable of photographing objects through a variety of colour filters) can reveal a surprising amount about the mineral properties of the rocks around them, while spectrometers – which study the light emitted when a target object is bombarded with radiation – can serve as chemical 'sniffers' to identify the signatures of specific elements and molecules that they find.

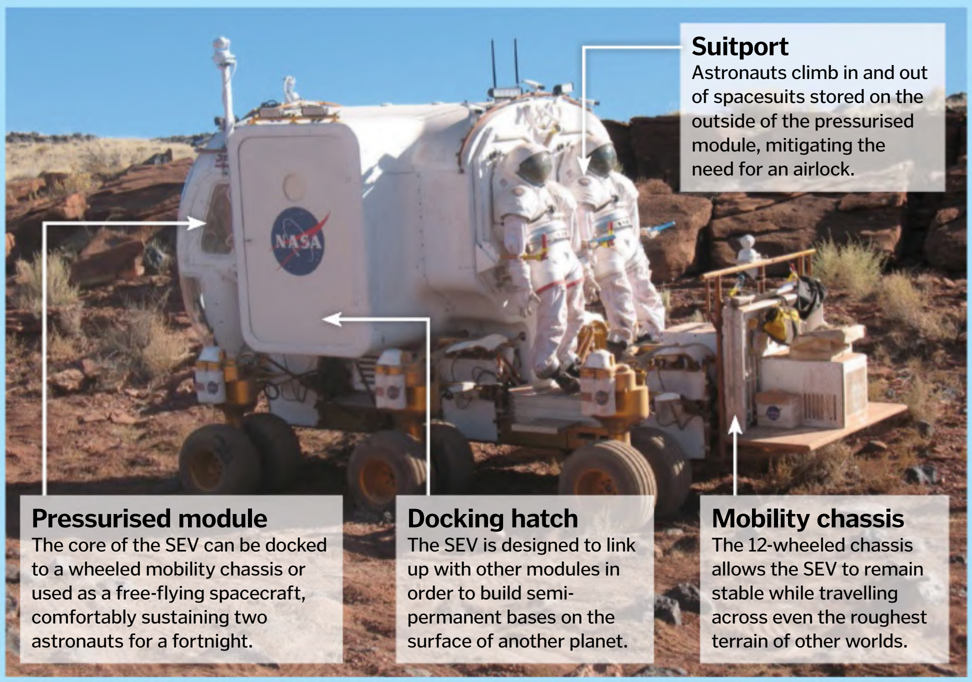
As rovers have become even more sophisticated, they have also improved their sampling abilities. The compact mini-rover Sojourner could only investigate rocks that were exposed at the surface, while Spirit and Opportunity were both equipped with a rock abrasion tool (RAT) that allowed them to expose fresh rock for study with the instruments on their robotic arms.

Curiosity and the planned ExoMars rover, meanwhile, are both equipped with special drills that enable them to collect subsurface rock samples and pass them to built-in chemical laboratories for analysis. Time will tell as to their success.

This sample of Martian rock drilled by Curiosity indicated the Red Planet could have once supported life

The SEV: rover of the future?

NASA's concept Space Exploration Vehicle is designed for space and surface missions



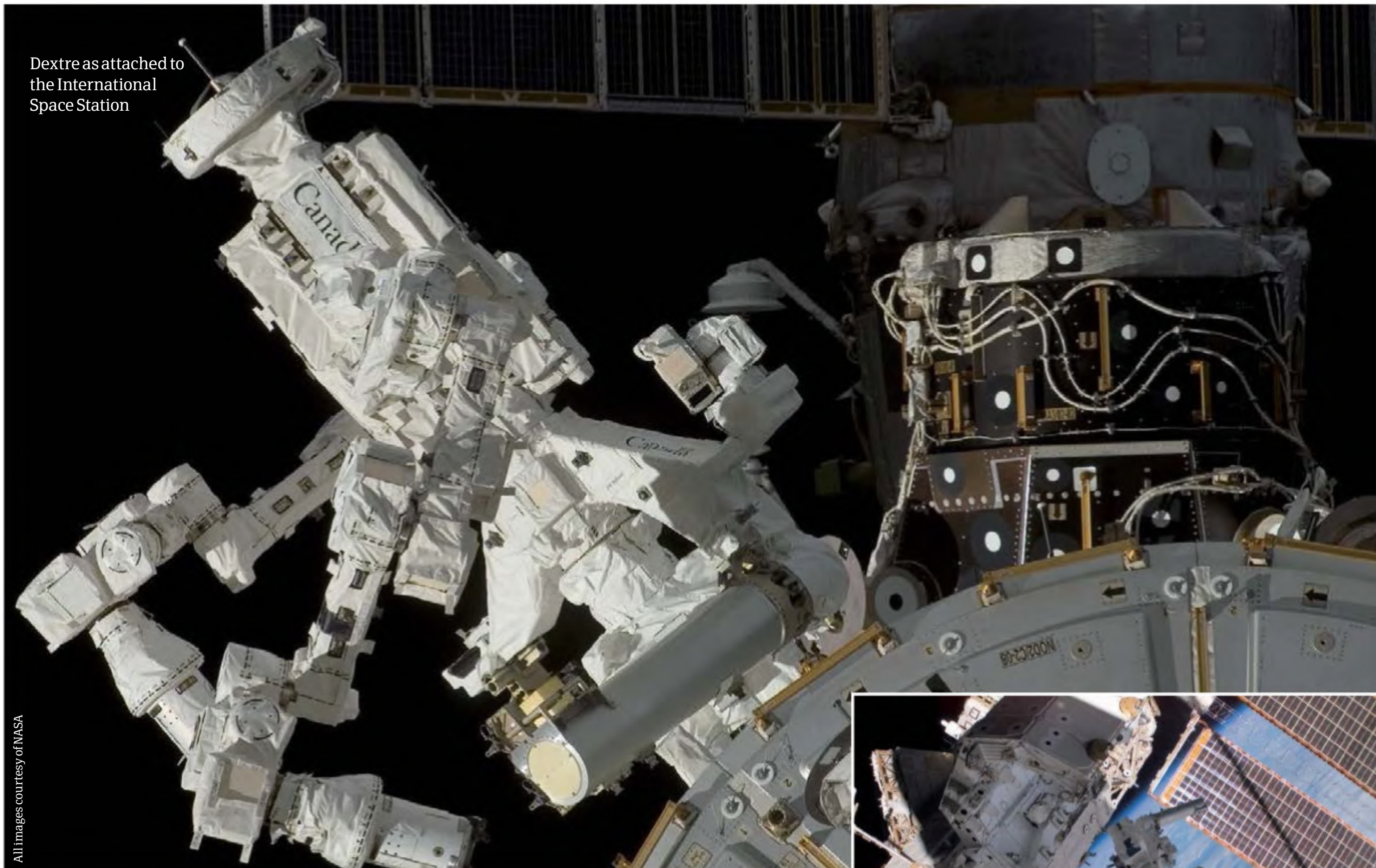
2010
After becoming stuck in 2009, the Spirit rover finally loses contact with Earth.

2011
Opportunity finds evidence for ancient water flowing through underground springs in Mars's Endeavour Crater.

2012
NASA's car-sized Curiosity rover touches down in the Gale Crater near the Martian equator.

2013
Curiosity uses its drill to sample rocks from beneath the Martian surface for the first time, discovering evidence for clays formed in hospitable Martian water.

2018
Currently scheduled landing of the European-built ExoMars rover, the first robot explorer specifically designed to search for signs of ancient life on the Red Planet.



Dextre as attached to the International Space Station

All images courtesy of NASA

Dextre being unpacked and readied for launch

Dextre the space robot

The robot that will fix the International Space Station

On the ISS, components sometimes need repair or must be moved for tests. Late in 2010, the Special Purpose Dexterous Manipulator, or Dextre, became operational after about two years of testing.

The primary reason for sending in a repair robot has to do with saving time for astronauts, who can focus on science experiments and because the robot is impervious to radiation and other space hazards. "Dextre also helps reduce the risk from micrometeorites or suit failures that astronauts are exposed to during an EVA (Extravehicular Activity)," says Daniel Rey, the manager of Systems Definition for the Canadian Space Agency.

Dextre is an electrical robot. It has two electrically controlled arms, each with seven degrees of movement. Each joint is controlled by a separate computer processor and runs a set of predetermined computer code. "CPUs control co-ordinated movements," says Rey, explaining that the robot is mostly controlled from the ground but does have some autonomous behaviour. "All the joints are rotary joints so they have to move in a co-ordinated fashion." The 3.67-metre tall robot weighs 1,560 kilograms and had to be 'orbitally assembled'. The colossal bot has four main tools it will use for repairs. Rey described the two important characteristics of Dextre which makes it the ultimate space repairbot.

First, Dextre uses an inverse kinematic engine to control joint movement. The 'inverse' is that the joints are instructed on the final place to move one of its repair tools, and then must work backwards and move joints to arrive at that position. Rey described this as similar to instructing a human to put a hand on a doorknob, and then knowing that you need to move an elbow, forearm, and shoulder to that position. A second characteristic is called forced moment sensor, which measures the forces applied on the joints and is used for correcting inputs from an astronaut to avoid errors and joint bindings.

The Statistics

Dextre

Height: 3.67 metres
Weight: 1,560 kilograms
Arm length (each): 3.35 metres
Handling capability: 600 kilograms
Crew: 98
Average operating power: 1,400 watts

The Mars Hopper

The Martian vehicle that will hop, skip and jump its way around the Red Planet

British scientists have designed a robot that could roam the Red Planet by jumping over 0.8 kilometres (half a mile) at a time. The Mars Hopper will tackle the rocky landscape by leaping over obstacles.

The Hopper measures 2.5 metres (8.2 feet) across and weighs 1,000 kilograms (2,205 pounds), which is slightly more than NASA's Curiosity rover. One hop could launch the vehicle up to 900 metres (2,953 feet) at a time. To achieve this, a radioactive thermal capacitor core will provide thrust through a rocket nozzle. The Martian atmosphere, thick in carbon dioxide, would provide the fuel as it is compressed and liquefied within the Hopper.

If successful, the Hopper would allow rapid exploration of Mars with tricky terrains like Olympus Mons and other hills, craters and canyons much easier to navigate. On current vehicles such as the Exploration rovers, the wheels have become stuck on slopes and the sandy, rocky texture of the planet's surface. The Hopper will use magnets in its four-metre (13-foot) leg span to allow it to leap again and again. The magnets will create an eddy current to produce a damping effect.

Proposed by experts from the company Astrium and the University of Leicester, the concept was first designed in 2010. A slight issue lies in the rate of CO_2 gathering, with the current system taking several weeks to completely fill the fuel tank. However, the vehicle will more often than not be at a standstill as it thoroughly scours the Martian landscape, so this should not pose an immediate problem.

The first-ever spacecraft to orbit Mars, NASA's Mariner 9

Martian exploration programmes

The first craft to attempt to explore Mars was launched way back in 1960 when the USSR's 1M spacecraft failed to leave Earth's atmosphere. After various unsuccessful launches by the USA and the Soviet Union, NASA's Mariner 9 became the first craft to orbit the planet in 1971. In 1975 the Viking 1 lander was the first to successfully touch down on the surface. The USSR managed to orbit Mars only weeks after the Mariner with their Mars 2 spacecraft but have not yet landed on the planet. The most recent lander is NASA's Curiosity, which was launched in 2011 and is tracking the Martian surface as we speak. The third organisation to get in on the act was the ESA (European Space Agency) who launched the Mars Express and Beagle 2 Lander in 2003. The Express has successfully orbited the planet but unfortunately communication was lost with Beagle 2 after its deployment. The most recent NASA craft is MAVEN, the Mars Atmospheric and Volatile EvolutioN, which launched in 2013 and will enter Martian orbit this September. Also in 2013, the Indian Space Research Organization (ISRO) launched its Mars Orbiter Mission (MOM) in its bid to become the fourth space agency to reach the Red Planet.

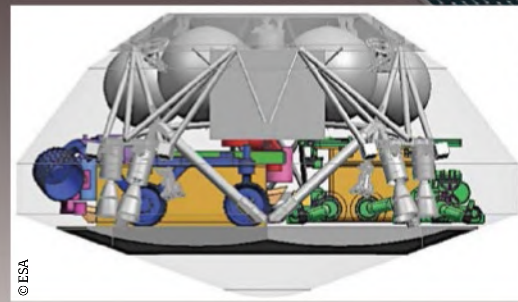
ExoMars robots

The most extensive search for life on Mars yet

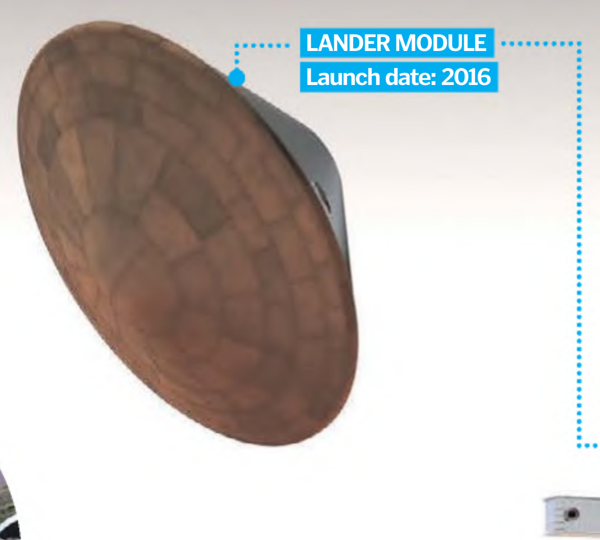
The primary goal of the ExoMars mission is to determine if life ever existed on the Red Planet. The European Space Agency (ESA) and NASA are working together on several robots to probe the planet like never before, and provide unprecedented data on the history and current composition of this fascinating world. It is hoped that the mission will provide the basis for a Mars Sample Return mission in the 2020s, and provide data for a planned human mission in the 2030s.

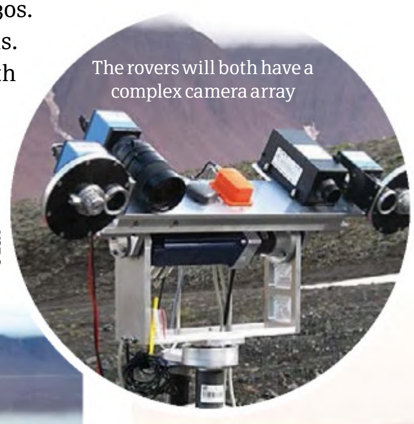
The mission has been dogged by alterations and cancellations. ExoMars was initially intended to launch by 2012 in tandem with a Russian spacecraft. Now, however, ESA has teamed with NASA and will launch two ExoMars missions aboard two Atlas V rockets in 2016 and 2018.

Here we look at the four machines that will travel to Mars, what their objectives are and how they will work.



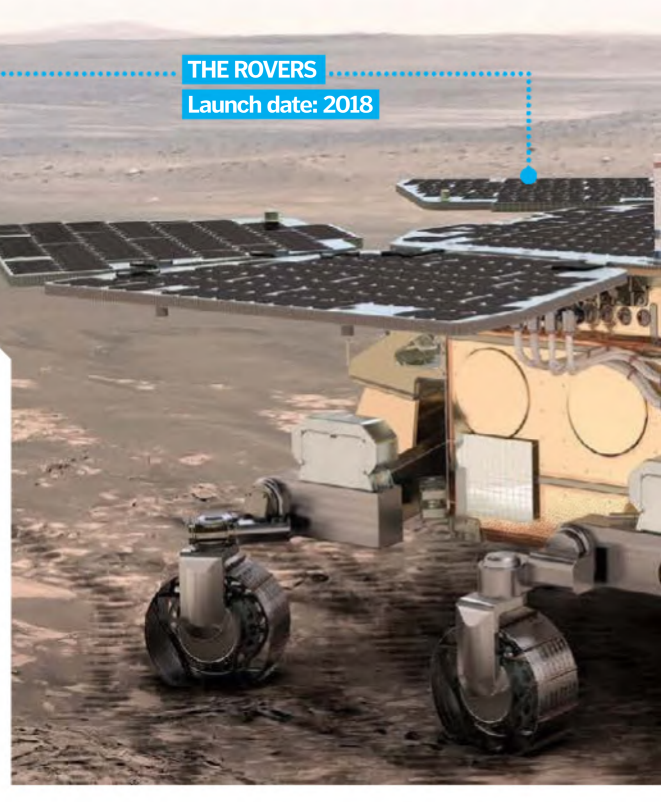
A 'Sky Crane' will lower the rovers to the surface





The rovers will both have a complex camera array

Testing for the prototype ESA rover is already underway



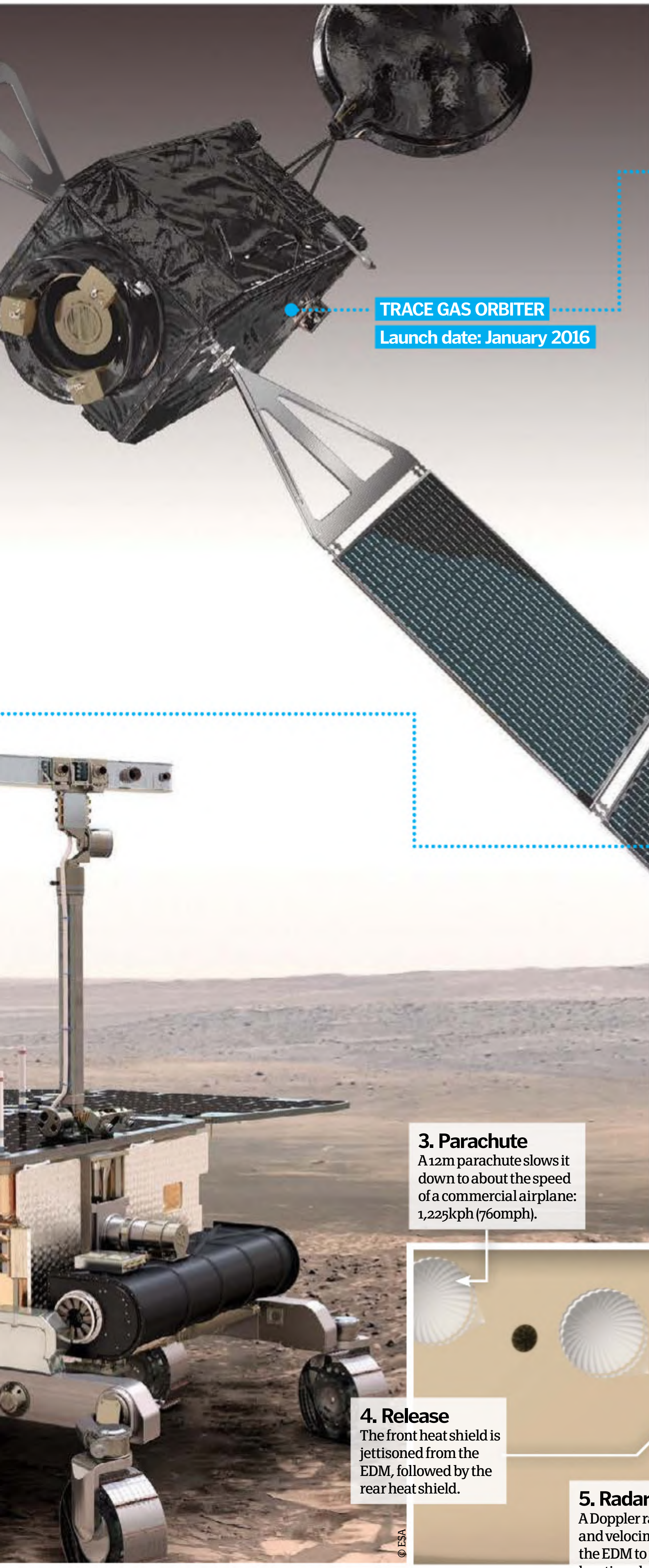
The rovers

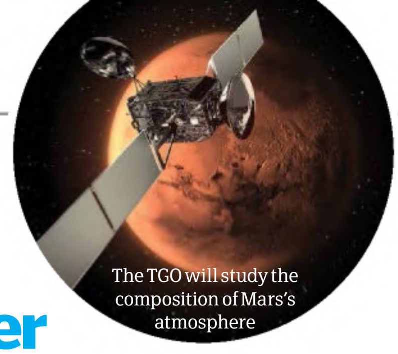
The 2018 NASA-led mission will see two rovers, one ESA-built and one NASA-built, work in tandem on the surface of Mars in the same area. The rovers will arrive nine months after their May 2018 launch date, travelling together but separating before atmospheric entry. The objective for both rovers is to land in an area of high habitability potential and search for evidence of life beneath the surface.

The aim of the ESA rover is to perform subsurface drilling and sample collection. Ground control will give it targets to reach based on imagery from the on-board cameras and instruct it to travel 100m (330ft) per sol (Martian day). Six wheels will drive the rover in addition to adjusting its height and angle, while gyroscopes and inclinometers will help it traverse soft soil. Its sample device can drill to a depth of 2m (6.5ft) to retrieve soil and study the subsurface borehole. Four instruments (the Pasteur payload), crush the soil into a powder and study its chemical and physical composition, before data (100Mbits per sol) is sent back to Earth via the ESA's orbiter.

NASA's Mars Sample rover (MAX-C) is still very much in its concept phase, yet its goal is clear: retrieve samples of Martian soil for collection. The mission raises the possibility that if the ExoMars drill on the ESA rover discovers signs of biology in a soil sample, the MAX-C rover could store the soil for collection by the Mars Sample Return mission in the 2020s and return them to Earth.

Following meetings in April 2011, NASA and ESA are considering combining the two rovers into one.

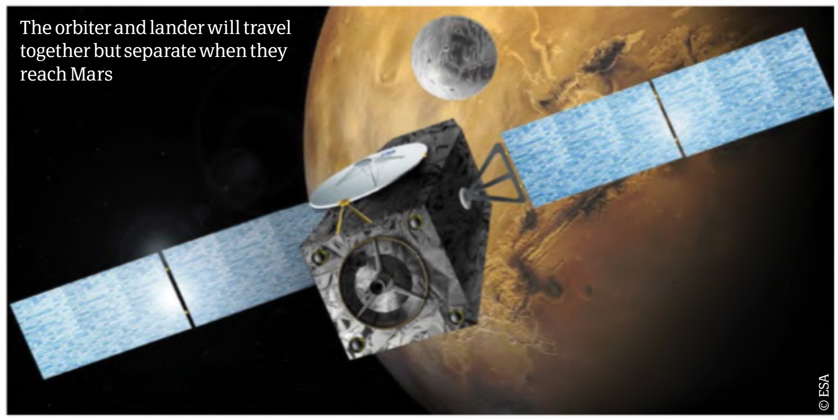



The TGO will study the composition of Mars's atmosphere

Trace Gas Orbiter

The ExoMars Trace Gas Orbiter (TGO) will be transported along with the Entry, Descent and Landing Demonstrator Module (EDM). It is the first mission of the ExoMars program, scheduled to arrive at Mars in 2016. The main purpose of this ESA mission is to detect and study trace gases in the Martian atmosphere such as methane, water, nitrogen dioxide and acetylene. By locating the source of gaseous releases on the surface, the TGO will determine an ideal landing site for the EDM that will follow in 2019.

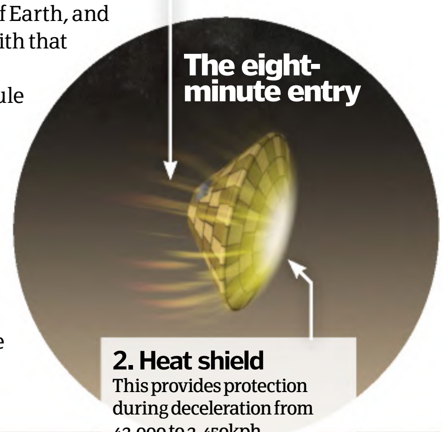
The TGO will be 11.9 metres (39 feet) long and use a bipropellant propulsion system. Two 20m² solar arrays will provide 1,800 watts of power, in addition to two modules of lithium-ion batteries for when the orbiter is not in view of the Sun. Together, these two power sources will allow the orbiter to operate for six years until 2022. Two antennas provide communication with both Earth and the rovers on the surface of Mars, while 125kg of science payload will gather data from the Martian atmosphere.


The orbiter and lander will travel together but separate when they reach Mars

Lander module

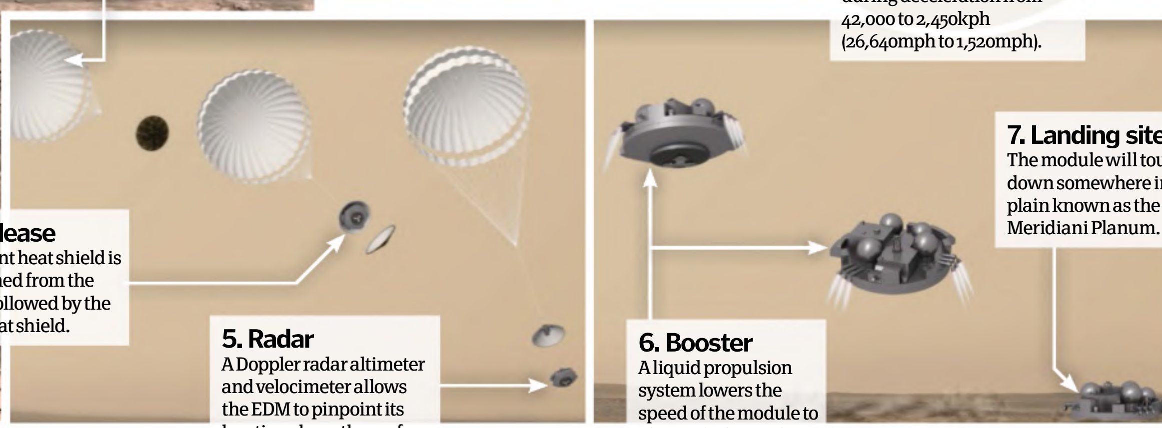
One of the reasons for any mission to Mars is the search for evidence of life, but a huge obstacle is actually landing on the planet. Its gravity is just 38% that of Earth, and its atmosphere is much, much thinner. With that in mind, the ESA's 2.4m (7.9ft)-wide Entry, Descent and Landing Demonstrator Module (EDM) will include limited science capabilities, instead focusing on performing a controlled landing and demonstrating a safe and reliable method to do so. It is more a tech-demo hitching a ride with the Trace Gas Orbiter than a standalone science station, but nonetheless it will provide data on future Mars landings. The science package that the EDM will deliver to the surface will operate for about nine days.

The eight-minute entry



1. Atmosphere
The 600kg EDM will first encounter the atmosphere of Mars at a height of 120km (75 miles) from its surface.

2. Heat shield
This provides protection during deceleration from 42,000 to 2,450kph (26,640mph to 1,520mph).



3. Parachute
A 12m parachute slows it down to about the speed of a commercial airplane: 1,225kph (760mph).

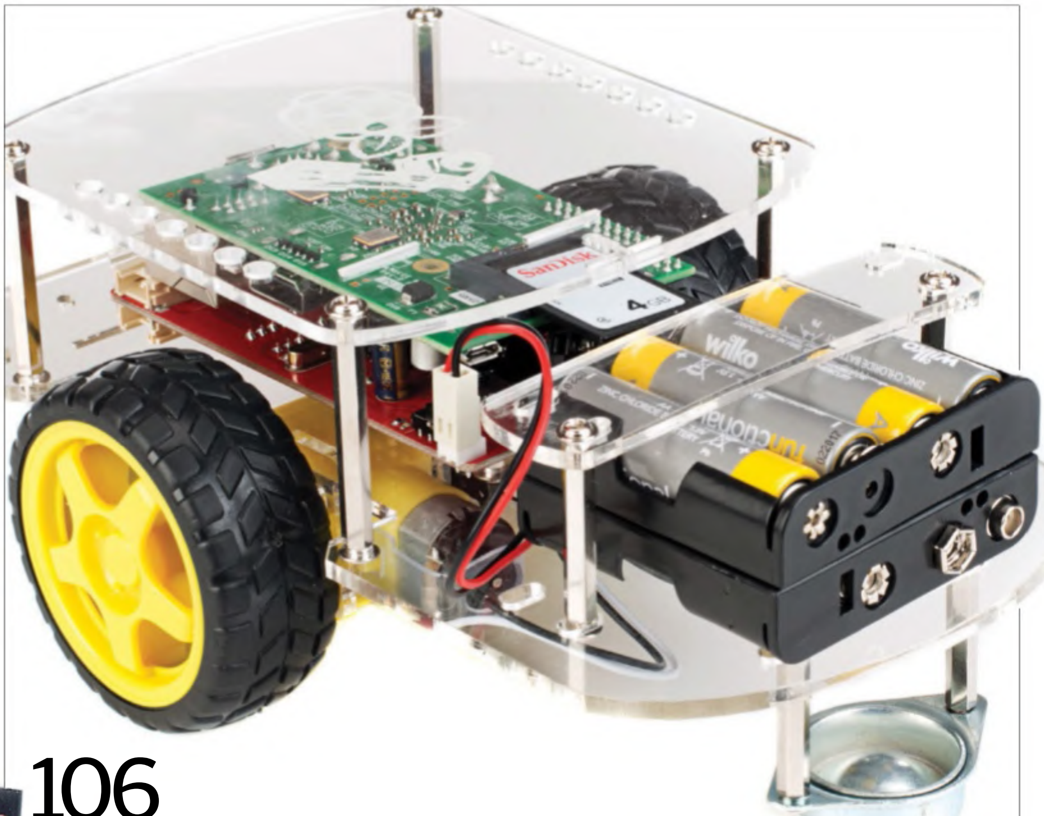
4. Release
The front heat shield is jettisoned from the EDM, followed by the rear heat shield.

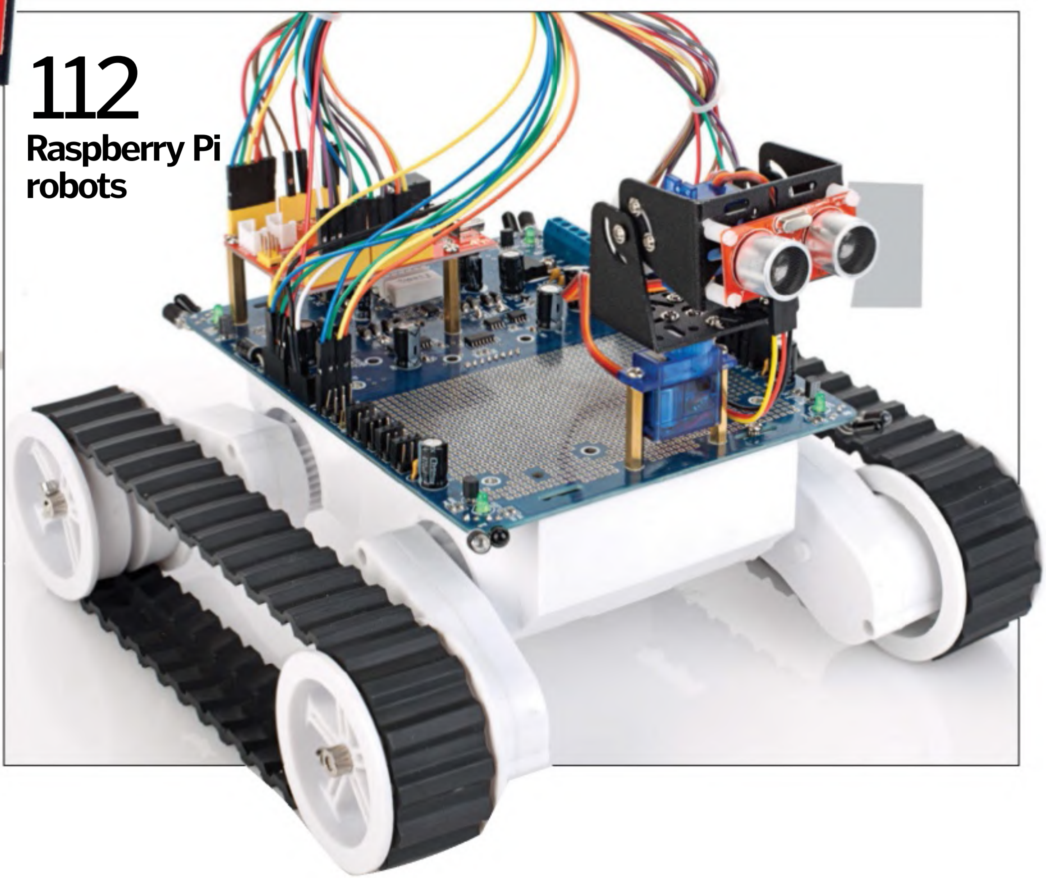
5. Radar
A Doppler radar altimeter and velocimeter allows the EDM to pinpoint its location above the surface.

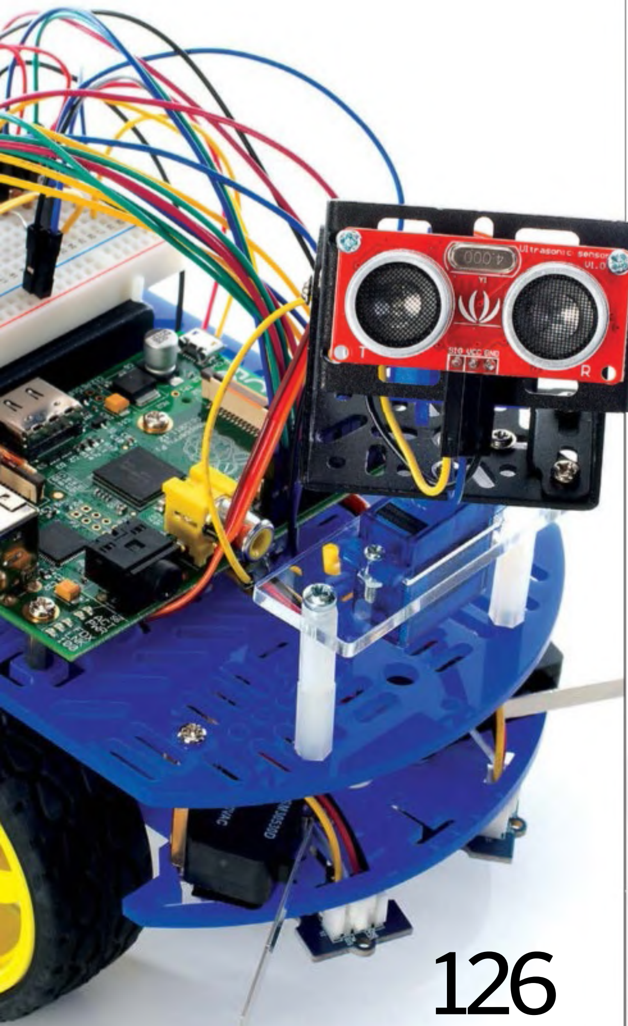
6. Booster
A liquid propulsion system lowers the speed of the module to about 15kph (9mph).

7. Landing site
The module will touch down somewhere in a plain known as the Meridiani Planum.

BUILDING ROBOTS


106
Build your first robot


112
Raspberry Pi robots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Make the ultimate Raspberry Pi robot

Robot building glossary

Robots are awesome, and with the Raspberry Pi, a little bit of code and a few other electrical bits and bobs you're going to learn how to make your own. Thanks to affordable mini-computers like the Raspberry Pi and easy-to-learn languages like Python, everyone can have a go at building and programming their own robot. Don't worry if you've never heard of an Arduino or GitHub, we'll guide you through everything you need to know.

Never picked up a Pi before? This is what they look like!

Arduino

An Arduino is a microcontroller, a basic form of computer that you can program to read and control connected devices, such as a light, motor or sensor. Inexpensive and often used by hobbyists, Arduinos are normally dedicated to controlling a single process. Several coding languages can be used to program it.

Breadboard

An electronic breadboard is useful for making temporary and experimental circuits. "Breadboard" can also mean prototype, as you can test new electronic parts and circuit designs. They house simple or complex circuitry without needing soldering which makes it reusable. Normally made of plastic, Breadboards have numerous pluggable contact points.

Coding

Code provides a set of instructions for your computer so it knows what you want it to do. All software, websites, games and apps are created with code. Computers don't understand English the way you and I do, so instead we write code in a programming language.

Flask

Flask is a type of web framework which means it gives you the tools and libraries to build a web application such as a website or blog. Known as Python's Flask Framework, it's small, powerful and written in the Python language.

GitHub

GitHub is like Facebook for programmers. It's an online code-sharing service and the largest online hub, or repository, of coding projects and Gits. A Git lets you easily manage, view and track changes to your source code and is known by programmers as a version control system.

GND Pin

Most electronic circuits, including the semiconductors used to power your computer or mobile phone, have a number of power-supply pins. One of these pins is referred to as the ground or 'GND' pin. It can carry a range of voltages and usually provides the negative power supply to the circuit.

GPIO

A General-Purpose Input/Output (GPIO) is a programmable pin on a circuit. GPIO behaviour can be controlled by the user. This includes enabling or disabling the pin as well as configuring it as an input or output. Most integrated circuits, including the Arduino and Raspberry Pi make use of GPIO pins.

Python

Named after Monty Python, it's a powerful and user-friendly programming language. Python is popular with programmers as it is efficient and has easy-to-understand syntax (the grammar, structure and order of the code). It's also open-source which means it is free for anyone to use.

Range detector/ sensor

A range sensor lets a device, such as a robot, determine where objects or obstacles are in relation to it without coming into physical contact. These can include sonic (sonar) or light-based (laser, infra-red or visible reflected light) proximity sensors. Range detection is useful for navigation .

Raspberry Pi

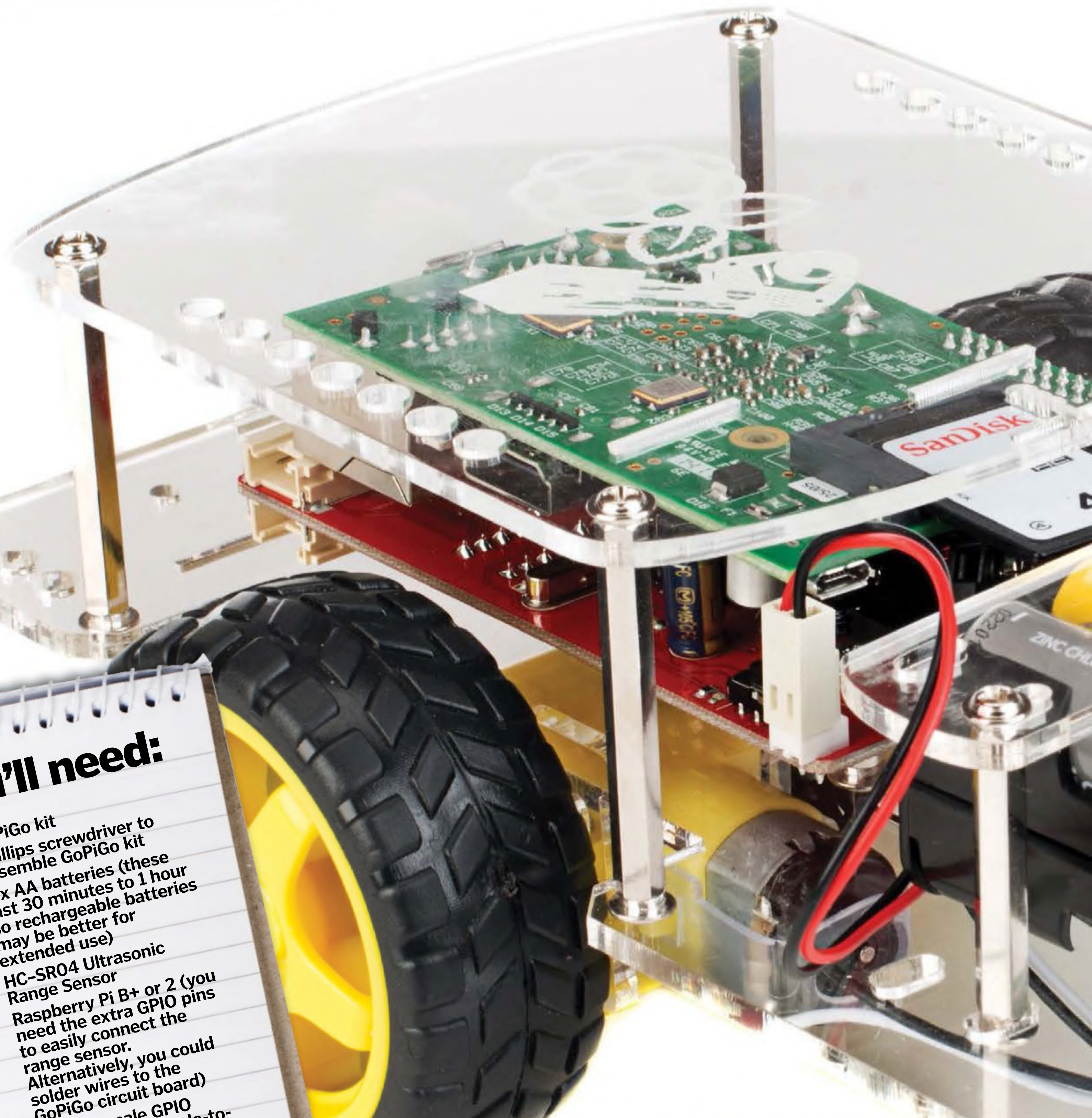
This low-cost, credit-card sized computer is designed to help people of all ages explore computing. It's a mini-desktop computer, able to browse the internet and even play HD video. Running the Linux operating system, a free alternative to Microsoft Windows, you can use it to learn programming languages like Python.

Resistor

A resistor is an electrical component that allows you to precisely restrict or limit the flow of current in a circuit. They can be used to protect components, split voltage between different parts of a circuit or control a time delay by providing a fixed or variable voltage.

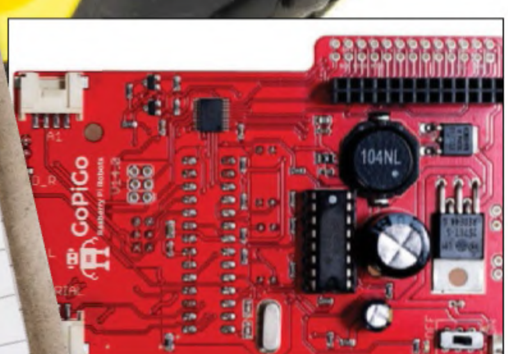
Text editor

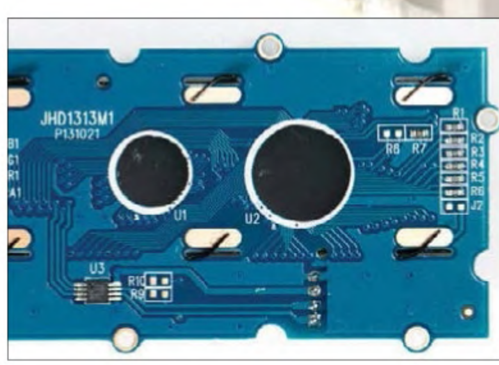
A text editor is a program that lets you edit plain text files. Whereas Microsoft Word or Apple Pages use their own special formatting for normal written languages, unique programming languages are better suited to more flexible and simple text editors. Sublime Text is a popular example.



You'll need:

- GoPiGo kit
- Phillips screwdriver to assemble GoPiGo kit
- 8 x AA batteries (these last 30 minutes to 1 hour so rechargeable batteries may be better for extended use)
- HC-SR04 Ultrasonic Range Sensor
- Raspberry Pi B+ or 2 (you need the extra GPIO pins to easily connect the range sensor. Alternatively, you could solder wires to the GoPiGo circuit board)
- Male-to-male GPIO jumpers and female-to-male GPIO jumpers
- A breadboard
- A 1k resistor and 2.2k resistor
- An SD card containing Raspbian Jessie
- A USB Wi-Fi dongle supported by a Raspberry Pi (the Raspberry Pi foundation recommend **www.raspberrypi.org/products/usb-wifi-dongle**)





BUILD YOUR FIRST ROBOT

Your robot will be a piece of DIY to be proud of once it's finished

Construct your own robot that can explore its surroundings and avoid obstacles. It can even be controlled with your phone and internet connection!

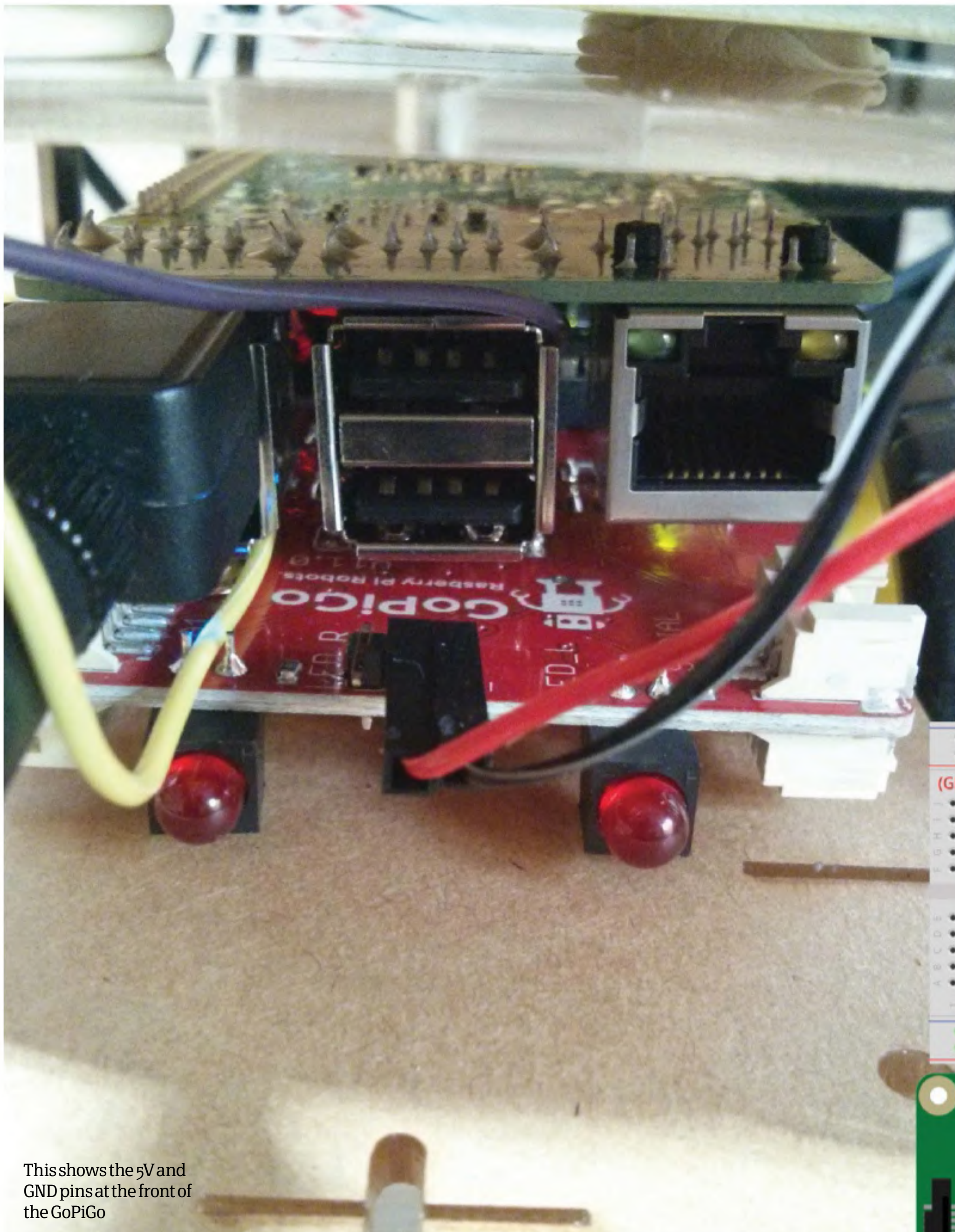
In this article we will build a Wi-Fi controlled robot in a using the GoPiGo kit (available from **www.dexterindustries.com/gopigo**). The GoPiGo contains the components to construct your own robot car, with a Raspberry Pi and a few extra bits of kit. The GoPiGo works well because it is entirely open source. This means that if you want to know how the kit works in more detail, you can go and read the source code on GitHub (**www.github.com/DexterInd/GoPiGo**). The schematics are also on GitHub and can be viewed in a program such as EAGLE. You can also add your own features to the firmware (which is actually an Arduino sketch) because the board can be reprogrammed directly from the Raspberry Pi.

The first step is to build the circuitry for the ultrasonic range detector and connect that to the Raspberry Pi. Then it's time to assemble the GoPiGo kit and connect the Raspberry Pi to it. Once the circuitry is built, we will write three Python applications. Each is designed so that it can be used as a component in another app. In this case, we'll write a module to communicate with the range sensor and obtains the distance to any obstacles detected by the sensor. This will then be included in a robot application which has the code to make the robot move around and explore its environment, using the range sensor to avoid obstacles. Finally, we will write a web robot application to control the movement module via a web interface. The robot we made looks slightly different to the one pictured, but the differences are only cosmetic.

How the kit works

If you ignore the battery pack and a couple of other components, the GoPiGo robot kit is essentially an Arduino connected to a Raspberry Pi. The Arduino communicates with the Raspberry Pi via a protocol called I²C (Inter-Integrated Circuit), pronounced I-squared-C. To put it simply, a pre-determined list of commands is sent from a library stored on the Raspberry Pi to the Arduino, which follows these commands to put tasks into action.

The Arduino is connected to the rest of the electronics on the board: the motor controller, the motor encoders, some LEDs, and the battery voltage detector. The motor controller is an SN754410 Quadruple Half-H Driver. An H driver is something that allows voltage to be applied across a load (in this case a motor) in both directions. This means that the motors can be moved forwards or backwards depending on the signal that you send to the controller. The motor encoder sends a signal back to the Arduino each time it detects the wheel has moved, allowing the software to compensate if one wheel is moving slower than the other.



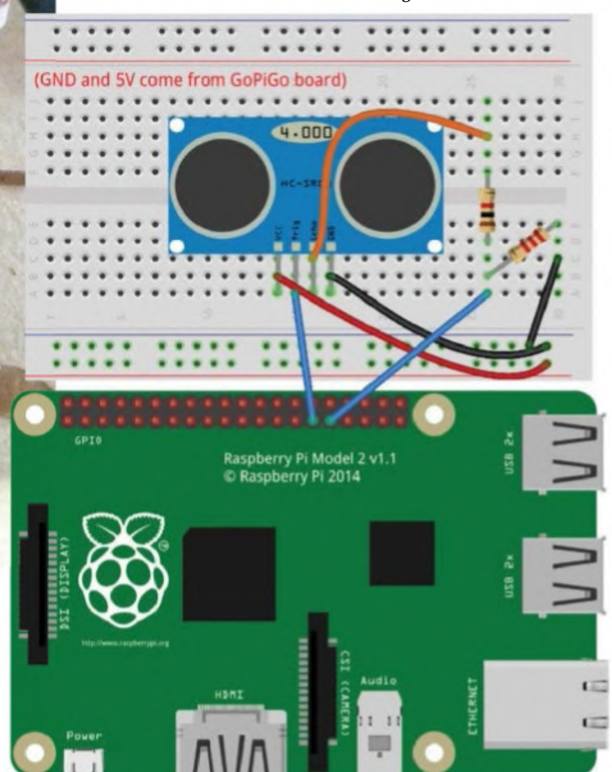
This shows the 5V and GND pins at the front of the GoPiGo

Make your bot bump-proof

Your robot needs a range detector circuit in order to avoid collisions. Build this according to the breadboard diagram shown below. The 5V and GND (ground) supplies are on the front of the GoPiGo. If you look at the board from the front (caster wheel at the back, wheels closest to the front side), you'll see there are three pins for connecting accessories. Luckily, the pin in the middle is a 5V, and on the right is a GND pin – we will use these to attach our supplies. If you have a multimeter, measure the voltage between those two pins to ensure you use the right one.

The resistors in the circuit act as a voltage divider. We need this because the Pi uses 3.3V for its GPIO pins, but the sensor needs 5V. By creating a voltage divider with a 1kΩ resistor from the signal, and a 2.2kΩ resistor to ground, we can reduce the 5V signal to a 3.3V signal.

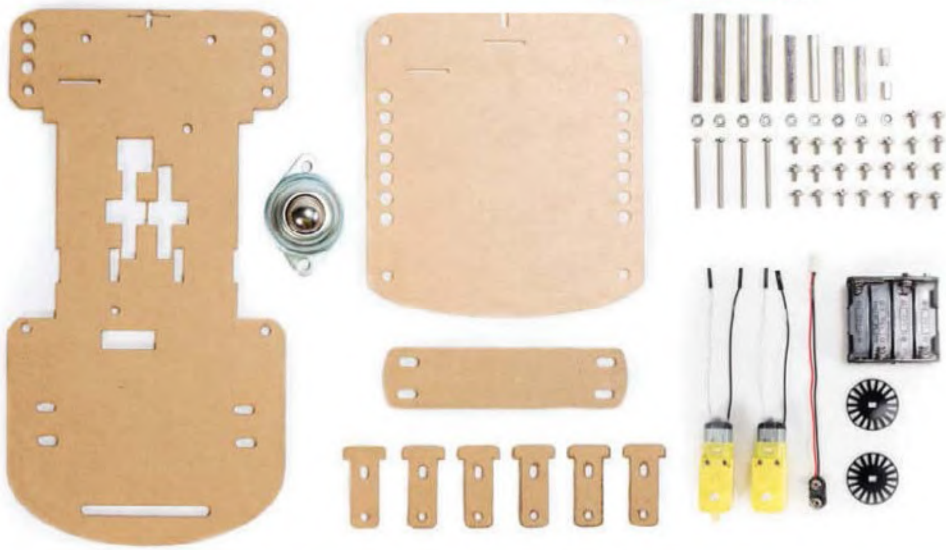
A breadboard view of the Ultrasonic Range Sensor circuit



> "The GoPiGo robot kit is essentially an Arduino connected to a Raspberry Pi. A list of commands is sent from a library stored on the Raspberry Pi"

Assemble the GoPiGo kit

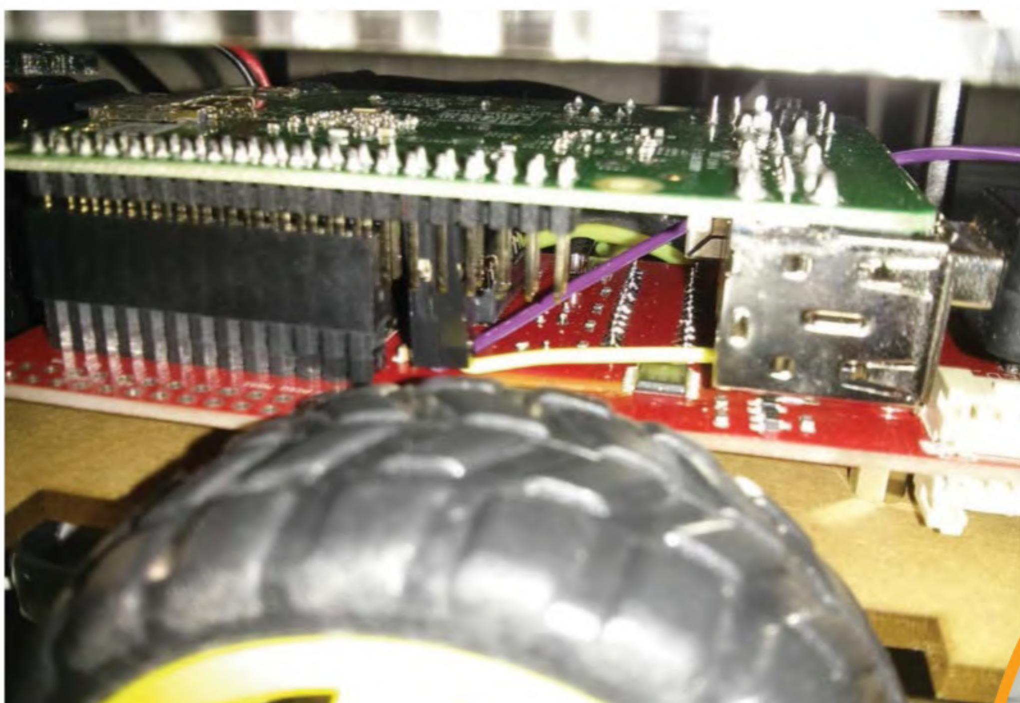
Detailed instructions for assembling the GoPiGo can be found on their website at this link: www.dexterindustries.com/GoPiGo/1-assemble-the-gopigo/assemble-gopigo-raspberry-pi-robot



How should it look?

Your Pi will look slightly different to the one in the pictures because we have the range sensor connected to the GPIO pins. However, the robot still connects to the Pi in the same place.

Assuming you used GPIOs 5 and 6 as in the diagram on page 108, there will be two pins between the connector on the GoPiGo board and where your first jumper cable is.



Save your battery life

It is important to think about how you will power your robot while you're testing it, otherwise it's likely you will drain your battery pack. While you are developing your software it is much better to connect the Raspberry Pi to power using a MicroUSB cable, and only use the batteries when you need to test the motors. The battery pack can be switched on with the On/Off switch on the GoPiGo circuit board so you don't have to disconnect it, and it will work even if the Raspberry Pi is connected to the MicroUSB supply. You may have to remove one of the struts that support the canopy of the robot to connect a MicroUSB cable to the Pi.

Take your robot online

These steps assume you are starting with a fresh Raspbian Jessie SD card. The first thing we'll do is set up a Wi-Fi connection so you can use your robot without any cables once it's using the battery pack.

You'll need to know your Wi-Fi network's name (the SSID), and the passphrase. Check that you can see your Wi-Fi network in the output of:

```
sudo iwlist wlan0 scan
```

Then edit /etc/wpa_supplicant/wpa_supplicant.conf with your favourite editor, for example:

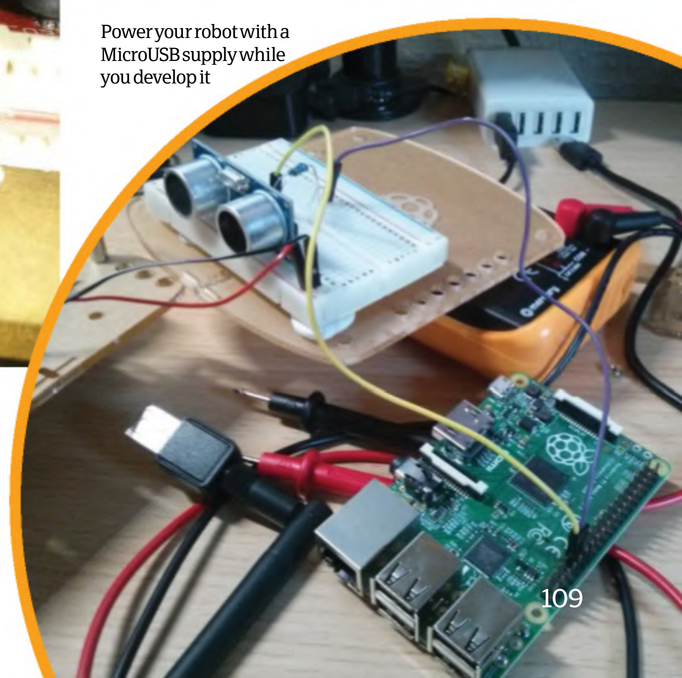
```
sudo nano /etc/wpa_supplicant/wpa_supplicant.
conf
```

Then append the following section, filling in the full details of your Wi-Fi network as appropriate.

```
network={
    ssid="The_ESSID_from_earlier"
    psk="Your_wifi_password"
}
```

Now reset the Wi-Fi interface with: sudo ifdown wlano; sudo ifup wlano. You should now be able to find out the Pi's IP address by running: ip -4 addr. Once you have the IP address you can connect to the Pi using SSH rather than needing a monitor and keyboard connected. If you get stuck finding your Raspberry Pi, try logging into your router and see if its address is there. Alternatively, you can Google "find Raspberry Pi on network" and find several results.

Once you have found the IP address log in via SSH using the default username of "pi" and the default password of "raspberry". This process is different for each operating system, so Google will help if you get stuck.



Power your robot with a MicroUSB supply while you develop it

Software setup

Once you are logged into the Pi, it's time to install the GoPiGo software. Before that, we'll do a general system update with:

```
sudo apt-get update
sudo apt-get upgrade
```

We then need to install Flask, which is a Python web framework we'll be using later on for the web interface:

```
sudo pip2 install flask
```

Then we need to clone the software from the GoPiGo GitHub repositry, and then use their setup script to install the required libraries.

```
git clone https://github.com/DexterInd/GoPiGo.
git
cd GoPiGo/Setup
sudo ./install.sh
sudo reboot
```

As an optional step, you can update the GoPiGo's firmware to ensure you run the latest version. Disconnect the motors to do this. Once the motors are disconnected, run:

```
sudo bash ~/GoPiGo/Firmware/firmware_update.sh
```

Test it out!

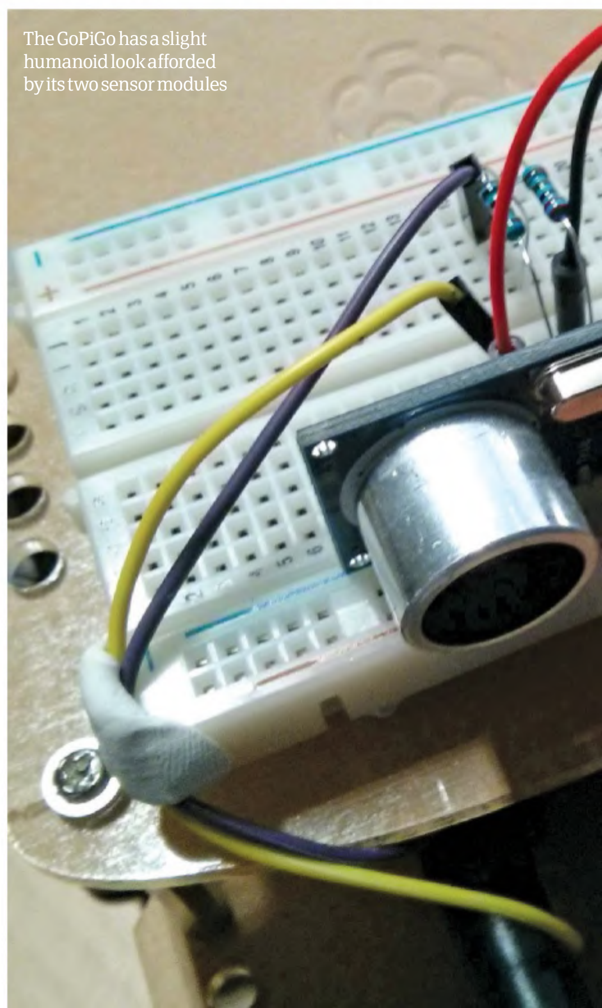
GoPiGo have provided a handy script which lets you test the features of the robot. We're going to use this to check the motors are connected correctly. You might want to prop the robot off the ground if the GoPiGo is on your desk to avoid it running off. Also make sure you switch the battery pack on.

Run the software with:

```
python2 GoPiGo/Software/Python/basic_test_all.py
```

You give commands by typing a character and pressing enter. The keys are: w for forward, s for backwards, a to turn the right wheel forward (resulting in a left rotation), d to turn the left wheel (resulting in a right rotation) and x stops the wheels. Both wheels should turn in the same direction when going forward. If not, then swap the white and black wires for one of the motors around. To ensure the orientation is correct, you should drive the wheels forward with the caster wheel facing backwards. If not, swap the wires on both motors. Once you have verified the motors are working correctly you can start writing your own software. Use Ctrl + C to edit the script.

The robot is so simple that any new Raspberry Pi user can make it



The GoPiGo has a slight humanoid look afforded by its two sensor modules

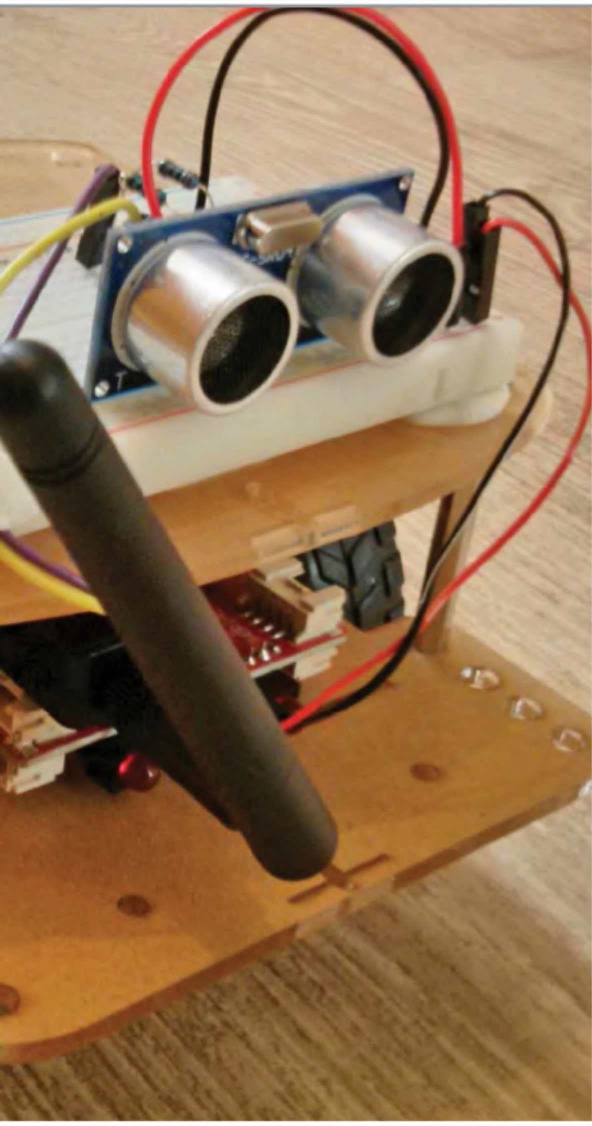
Range sensor software

Now it's time to write the range sensor software. It works by sending a trigger signal to the range sensor, then timing how long the echo pin stays high for. This lets us calculate the distance to the object in front of the sensor. You can write the script in any editor.

Run the script with Python 2 RangeSensor and it will print the distance to a detected object. It doesn't have to be totally accurate, you just have to find a threshold where something is too close and use that number.

RangeSensor.py

```
#!/usr/bin/env python

import RPi.GPIO as GPIO
import time

class RangeSensor:
    def __init__(self, triggerPin, echoPin):
        self.triggerPin = triggerPin
        self.echoPin = echoPin

        # Set up GPIO pins
        GPIO.setmode(GPIO.BCM)
        GPIO.setup(self.triggerPin, GPIO.OUT)
        GPIO.setup(self.echoPin, GPIO.IN)

        # Wait for sensor to settle
        GPIO.output(self.triggerPin, False)

    def trigger(self):
        # Sends trigger signal by setting pin high
and then low again
        GPIO.output(self.triggerPin, True)
        time.sleep(0.00001)
        GPIO.output(self.triggerPin, False)

    def readEcho(self):
        # Wait for pin to go high with failsafe in
case we miss signal
        startTime = time.time()
        while GPIO.input(self.echoPin) == 0 and \
              (time.time() - startTime < 0.1):
            startTime = time.time()

        # Now wait for pin to go low
        endTime = time.time()
        while GPIO.input(self.echoPin) == 1 and \
              (time.time() - startTime < 0.1):
            endTime = time.time()

        duration = time.time()
        return endTime - startTime

    def getDistance(self):
        self.trigger()
        duration = self.readEcho()

        # Using Speed = Distance / Time
        # Speed of sound = 340 metres per second
        # Sound needs to get to object and back so
170 metres per second
        # Distance = 170 metres per second (aka
170000 cm per second) * Time
        distance = 170000 * duration

        # Round distance in CM to 2 dp
        return round(distance, 2)

if __name__ == "__main__":
    # Small test program
    rangeSensor = RangeSensor(triggerPin = 6,
                              echoPin = 5)

    while True:
        d = rangeSensor.getDistance()
        print "Distance is {0}cm".format(d)
        time.sleep(1)
```



Robot software

The Robot software is in two parts: a Robot class with no web interface, and something that puts a simple web application on top of the robot class. As with the range sensor code, both are fairly simple. The WebRobot needs a web page to display to the user (called index.html). It has buttons corresponding to an action. For example, the stop button connects to the web server and sends a "/stop" message. Upon receiving this, the app stops the bot. Flask runs on port 5000 by default. Here, the web interface address was 172.17.173.53:5000.

Robot.py

```
#!/usr/bin/env python

from RangeSensor import RangeSensor
from gopigo import *
import random

class Robot:
    def __init__(self):
        self.rangeSensor = RangeSensor(triggerPin
= 6,
                                       echoPin =
5)
        self.rangeThreshold = 150
        set_speed(100)
        self.shouldExplore = True

    def _explore(self):
        print "Going Forward"
        fwd()
        while self.rangeSensor.getDistance() >
self.rangeThreshold:
            time.sleep(0.01)

        # We have found an obstable
        stop()
        print "Found an obstacle"

        # Rotate a random amount in a random
direction
        if random.randrange(0, 2) == 0:
            print "Rotating left"
            left_rot()
        else:
            print "Rotating right"
            right_rot()

        # Sleep for 1 to 5 seconds
        time.sleep(random.randrange(1000, 5001) /
1000.0)

    def explore(self):
        self.shouldExplore = True

        try:
            while self.shouldExplore:
                # Don't use all cpu
                time.sleep(0.1)
                self._explore()
        except KeyboardInterrupt:
            # Stop the robot before exiting
            stop()

    # Simple direction functions for web server
    def stopExplore(self):
        self.shouldExplore = False

    def stop(self):
        stop()

    def forward(self):
        fwd()

    def left(self):
        left_rot()

    def right(self):
        right_rot()

if __name__ == "__main__":
    r = Robot()
    r.explore()
```

WebRobot.py

```
#!/usr/bin/env python

from flask import Flask, send_from_directory
app = Flask(__name__)

from Robot import Robot
robot = Robot()

import thread

@app.route("/")
def index():
    return send_from_directory("/home/pi/robot",
"index.html")

@app.route("/stop", methods=['GET', 'POST'])
def stop():
    robot.stopExplore()
    robot.stop()
    return 'OK'

@app.route("/left", methods=['GET', 'POST'])
def left():
    robot.left()
    return 'OK'

@app.route("/right", methods=['GET', 'POST'])
def right():
    robot.right()
    return 'OK'

@app.route("/forward", methods=['GET', 'POST'])
def forward():
    robot.forward()
    return 'OK'

@app.route("/explore", methods=['GET', 'POST'])
def explore():
    thread.start_new_thread(robot.explore, ())
    # Thread will exit when we call /stop
    return 'OK'

if __name__ == "__main__":
    app.run(host='0.0.0.0')
```

RASPBERRY PI ROBOTS

Discover the best robotics kits around and learn to program them with your Raspberry Pi or Arduino

The rise of our robot overlords is well underway – give it another five years and we'll all be watched over by Pi-powered machines of loving grace. In the meantime, though, we've rounded up the very best DIY robotics kits available to buy right now that are designed to work with your Raspberry Pi, so you can get a head start on the inevitable revolution (and befriend the bots before they become our overlords). Whether they are Arduino or Raspberry Pi-based, we're getting all of our robots to listen to our master Pi controller and we're going to show you how to do the same with your kit.

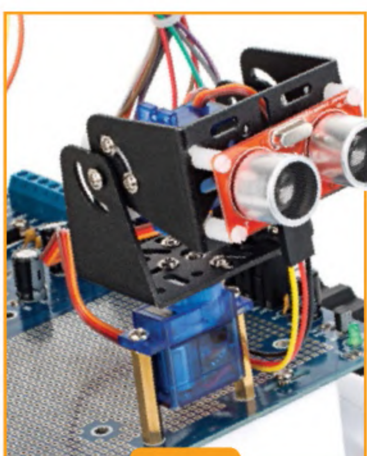
We'll also be scoring these robotics kits to identify their strengths and weaknesses in terms of their build quality, functionality out of the box, the construction process and of course their programmability, to help show you which kit is right for you and where you can get hold of your own.

And what then? Well, we thought we'd put our robots to the test with a series of gruelling challenges. Not content to stop there, though, we also reveal how to get one of your robots to play a mighty fine round of golf (for an automaton, at least – we doubt Rory McIlroy will be quaking in his golf shoes) and another two to battle each other (sumo style).

So it's time to introduce you to our hand-picked team of robots – some of whom you might recognise from the book so far.

Over the next few pages you'll meet Rapiro, our most humanoid robot (who you can see in all his glory on the right) and our good friend from pp. 106-111, GoPiGo plus the similar bot Pi2Go, both being nippy little two-wheel tricars with ball-bearing casters for stability. You'll also meet Frindo, the sensor-loaded, open source mobile robotics platform; Rover 5, the rugged two-track tank with a Seeeduino brain and an inexorable top speed of 1km/s; and Hexy, the six-legged, crab-walking, Thriller-dancing (bit.ly/1lj2CqR) force of robotic nature.

So grab your pocket computer of choice and get ready to advance the field of robotics in your own home, with these little mechanical critters.



Rover 5

Pi2Go

Frindo

Hexy the Hexapod

GoPiGo


Rapiro

Rover 5 Seeeduino

A relative monstrosity, the Seeeduino is fully kitted out and makes a great gift

TECH SPECS

Manufacturer
Dawn Robotics

Height
170 mm

Width and depth
225 x 235 mm

Weight
1.05 kg

Power
9 volts from 6 AA batteries

Control board
Seeeduino Arduino (ATmega 328P)

Form of locomotion
Two treads powered by four motors

Sensors
Ultrasonic and four corner-mounted infrared sensors

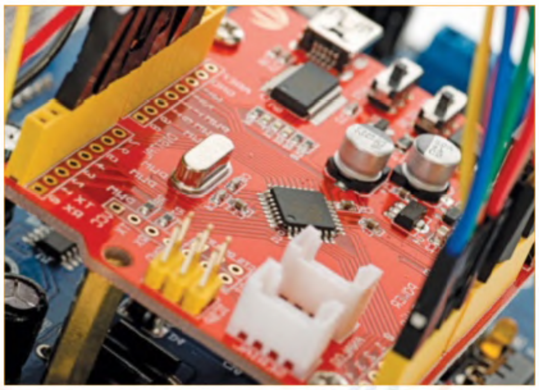
Website
www.dawnrobotics.co.uk

Dawn Robotics are not new to the robot-making market, and have produced a slew of innovative Pi robots including a chassis with a camera –and the Rover 5 is sort of a successor to that kit. The Rover 5 is a lot larger and generally has a few more functions than that particular Raspberry Pi robot. Said Raspberry Pi is not needed for the Rover 5 as it is fully powered by the Seeeduino, another ATmega 328P.

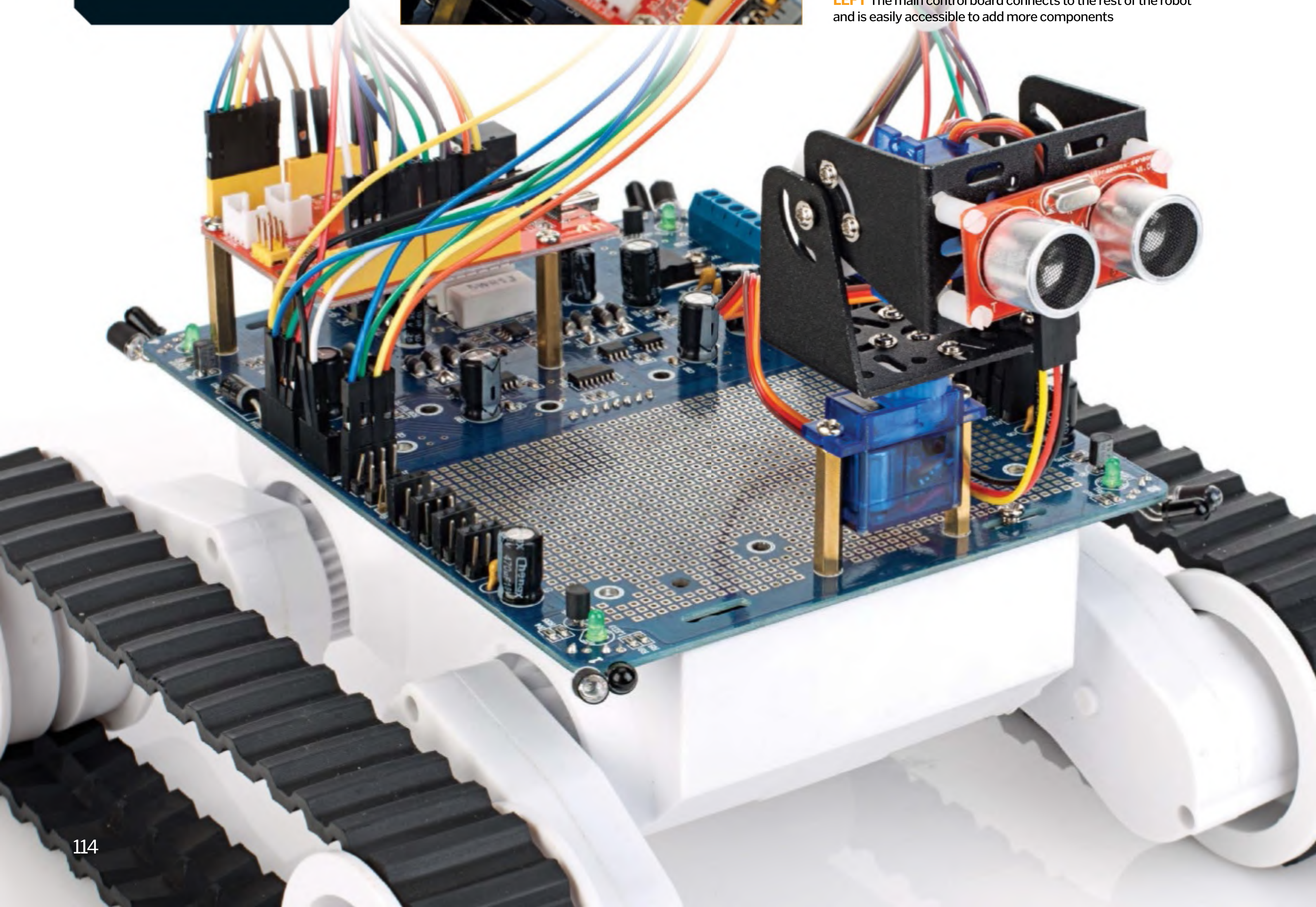
Construction is not the easiest and requires an extra hand at times. There's no soldering involved but there are an enormous amount of wires that connect up the board. Couple this with some extremely fiddly nuts and bolts, a manual that is sometimes a bit unhelpful, the odd cheap screw and you get a few problems that take a bit of lateral thinking in order to find a solution. The whole kit is a mixture of different components manufactured separately, which explains some of the discrepancies in the screws and how cobbled together the entire thing actually is.

The big board sits on top of the Rover 5 and is quite well suited for the kit, but it does contribute to the DIY, mashed-together look of the Rover 5 with all the wires flying around.

Programming it is slightly harder than other robots due to using pure Arduino rather than having serial commands or Python functions. You'll need to get right into the code to start programming, however there are some preset tutorial scripts that give pointers on how to create your own code. With the sensors on each corner of the Rover 5, the board and robot can react to almost any obstacle thanks to their coverage, not to mention the ultrasonic sensor also attached to it.



LEFT The main control board connects to the rest of the robot and is easily accessible to add more components



Code listing

```
const int NUM_IR_SENSORS = 4;
const int IR_LED_PINS[ NUM_IR_SENSORS ] = { A0, A0, A1, A1 };
const int IR_SENSOR_PINS[ NUM_IR_SENSORS ] = { A3, A2, A4, A5 };

...

float ultrasonicRange = gUltrasonicSensor.measureRange();
    gRoverIRSensors.takeReadings();
    int frontLeftIR = gRoverIRSensors.lastFrontLeftReading();
    int frontRightIR = gRoverIRSensors.lastFrontRightReading();
    int rearLeftIR = gRoverIRSensors.lastRearLeftReading();
    int rearRightIR = gRoverIRSensors.lastRearRightReading();

...

case eRS_DrivingForwardsLookingForWall:
        {
            // Check to see if we've hit an obstacle we didn't see
            if ( gLeftMotor.isStalled()
                || gRightMotor.isStalled() )
            {
                enterBackingUpState();
            }
            else
            {
                // Check to see if we've found a wall
                if ( ultrasonicRange <= CLOSE_ULTRASONIC_RANGE
                    || frontLeftIR >= CLOSE_RANGE_IR_VALUE
                    || frontRightIR >= CLOSE_RANGE_IR_VALUE )
```

```
                {
                    enterTurningLeftState();
                }
            }

            break;
        }

...

void enterFollowingWallOnRightState()
{
    // Point the ultrasonic sensor to the right
    gPanAngle = LOOK_RIGHT_PAN_ANGLE;
    gTiltAngle = LOOK_RIGHT_TILT_ANGLE;

    gPanServo.write( gPanAngle );
    gTiltServo.write( gTiltAngle );

    gLeftMotor.clearStall();
    gRightMotor.clearStall();

    gLeftMotor.setTargetRPM( BASE_WALL_FOLLOWING_RPM );
    gRightMotor.setTargetRPM( BASE_WALL_FOLLOWING_RPM );

    gStateStartEncoderTicks = gLeftMotor.getLastMeasuredEncoderTicks();
    gStateStartTimeMS = millis();
    gRobotState = eRS_FollowingWallOnRight;
}
```

Get the code
bit.ly/1uQzsNa

First motor test

No tires or drill instructors, but the robot still needs to navigate a maze of challenges

Kept top secret by the Pi Wars organisers, at the time of writing we can only guess at what kind of robot-destroying tasks are planned. The challenge they have set is for remote-controlled bots, but we're going to change the rules slightly and rely a bit more on automation. In our scenario, we're using a walled maze that runs a specific yet random course that the robot needs to navigate without any kind of lines to guide a robot with line sensors. It's a little more tailored to the Rover 5's capabilites, but how so?

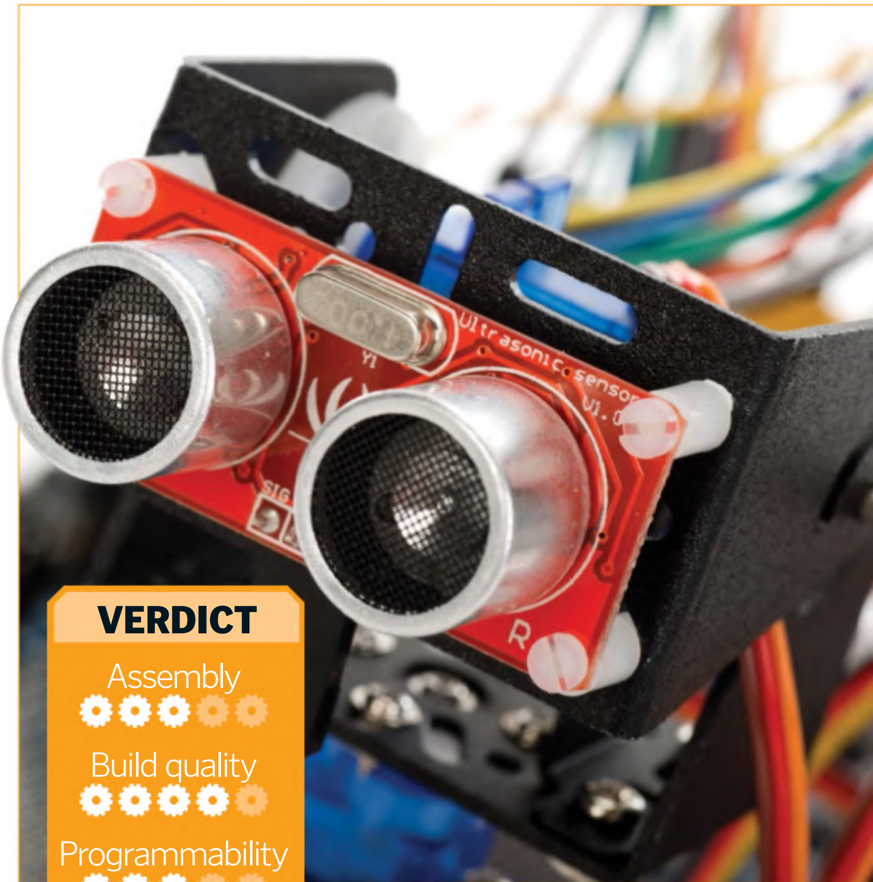
In this challenge, the Rover 5 is perfectly equipped to handle pretty much any course we can throw at it. Thanks to its array of proximity sensors, it will know if there's a wall in the way around its body. We can also use the ultrasonic sensor to figure out its distance from the wall and the way that the wall will change as you travel along the course.

There's some great code for the Rover 5 that allows you to follow a wall along the right of the robot. You can grab it here with the URL **bit.ly/1vp2LLZ**. Upload it via Arduino; it's a bit of a long task, but we will help you out by explaining some parts of it here. Firstly, there are a lot of setup integers created to begin with. These include defining minimums for speed, wall proximity and defining the sensors in general.

Next, we have a small part of the sensing code. All the readings are taken and turned into useful data for the rest of the code – in this case, integers. After that, we have one of the various movement sections. This is used to just move forward, looking to see where an obstacle/wall will be and beginning the chain of events that occurs after noticing or bumping into a wall. This will include backing up, turning left and turning right.

Finally, the code ensures that the sensor keeps an eye on the wall as it runs along it to make sure it's still there.

> "The Rover 5 is perfectly equipped to handle any course"



ABOVE The ultrasonic sensors enable the Rover 5 to sense distance to avoid collisions

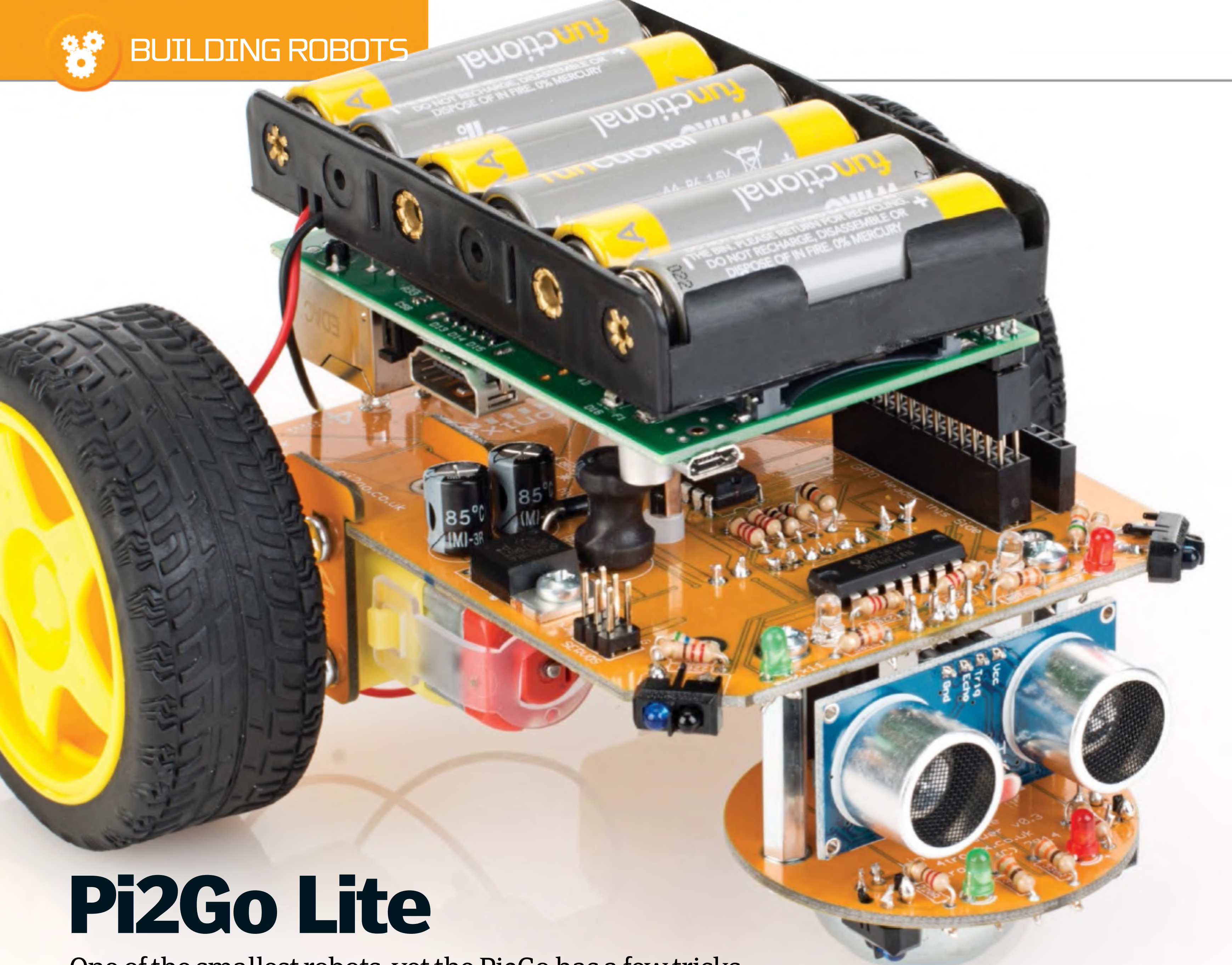
VERDICT

Assembly

Build quality

Programmability

Functionality



Pi2Go Lite

One of the smallest robots, yet the Pi2Go has a few tricks

TECH SPECS

Manufacturer
4tronix

Height
90 mm

Width and depth
130 x 145 mm

Weight
0.40 kg

Power
9 volts from 6 AA batteries

Control board
Raspberry Pi

Form of locomotion
Two-wheel drive

Sensors
Ultrasonic sensor, two line sensors and two IR obstacle sensors

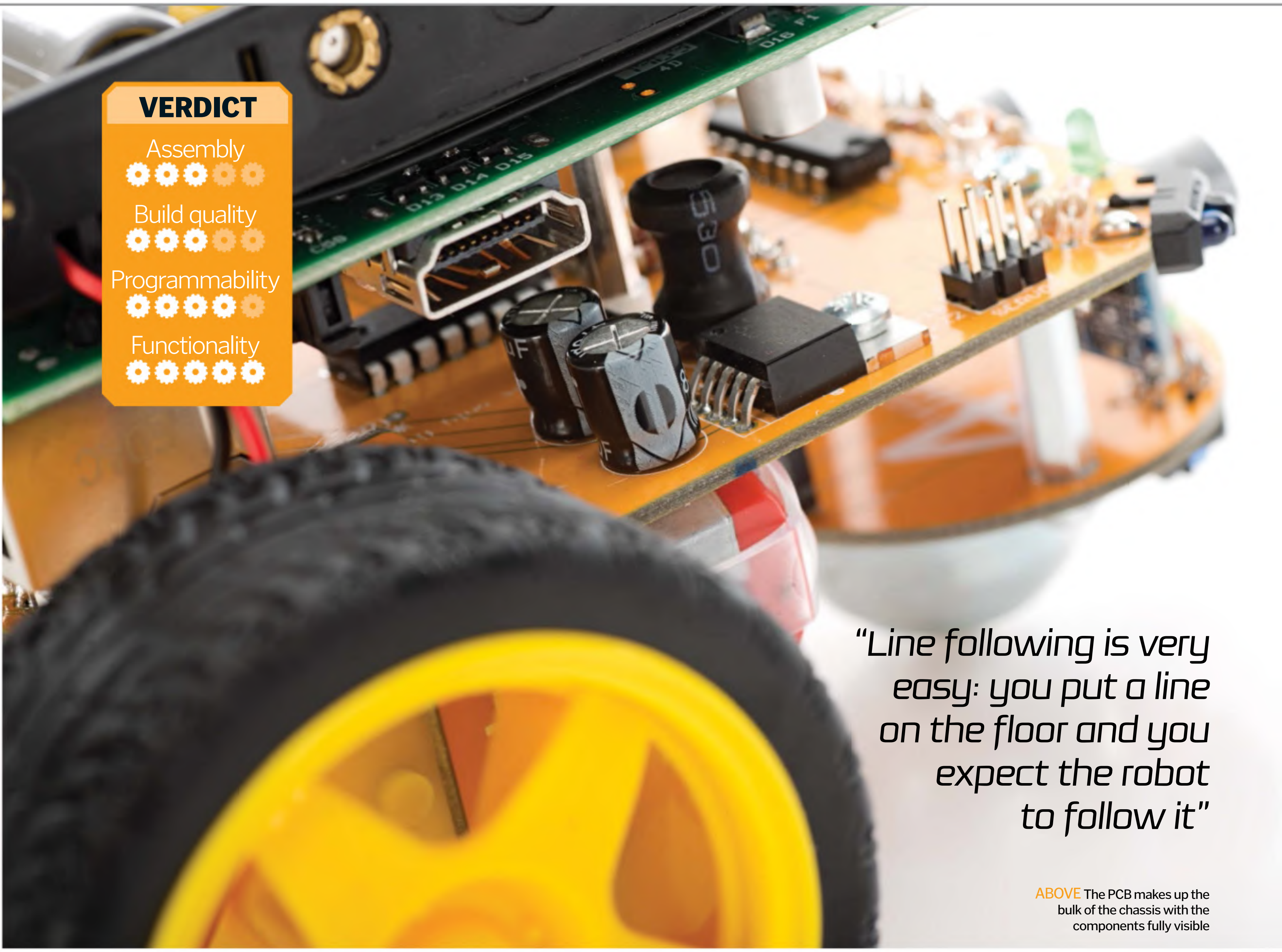
Website
www.pi2go.co.uk

The Pi2Go Lite is a very interesting little bit of kit. Coming in a tiny little box and utilising no chassis, in favour of construction via its PCBs, you'd think it would be a super simple robot that follows commands and doesn't really react much to the environment. It makes it sound like a remote control novelty more than anything else. That couldn't be further than the truth, as the Pi2Go is probably the most featureful robot we tested.

All this functionality comes at a price though, as it's the only robot that requires a lot of soldering and pre-preparation before construction. You'll need to be a bit handy with a soldering iron to do it, although you don't need to strip any wires and such. There are about 50 components to fit, possibly more, and it can be a little time-consuming. The instructions are not extremely helpful, but the individual components are actually listed on the PCB as a rough guide to where things should be fitted. Once the soldering is done though, you just need to put the few parts together to complete it. The website lists a 90 minute construction time, but we found it took somewhat longer – it was no longer than any of the bigger or more complicated robots on the other pages though.

It's a sturdy, compact little thing and it's powered purely by the Raspberry Pi via a custom Python library. Sensing, turning on the LEDs, activating the motors and other physical functions have their own corresponding Python function. It lets you create scripts that can make it fully autonomous, as long as the autonomy only requires distance, line and proximity sensing to operate. At least it can take extra timed or web information from the Raspberry Pi if that's set up correctly.

For the price, functionality and relative ease of programming, it's a fantastic piece of kit that's great for getting into starter-level robotics and slightly beyond. Some soldering skills required though.



VERDICT

Assembly ●●●○○

Build quality ●●●○○

Programmability ●●●●○

Functionality ●●●●●

> "Line following is very easy: you put a line on the floor and you expect the robot to follow it"

ABOVE The PCB makes up the bulk of the chassis with the components fully visible

Line following

Follow the black painted line, although you may not find a wizard at the end of it

Line following is very easy: you put a line on the floor and you expect the robot to follow it. This includes turning as well, following a course accurately to its destination or to accumulate laps. The Pi2Go Lite is the only robot we're looking at that comes equipped with line-following sensors, although it is the main unique feature. Sounds like it should be quite simple then, however there's no line-following function in the Python script so we need to build a script for it.

As we said, the solution involves the line-following sensors – these are IR sensors located on the underside of the smaller PCB where the caster sits. We'll assume we've placed the Pi2Go down on the line and you want to go straight forward along it. One of the problems we're going to run into is that the motors will likely not run at the exact same speed – with a bit of trial and error you can maybe fix this in the first forward command, but for now we'll keep it at 50, which is 50 per cent of its full speed. You can tweak this to be faster or slower as you see fit.

The loop is quite simple: it sees if any of the line sensors are activated. As we're assuming that the line is under the caster wheel, we'll need to correct course in a specific direction for each true statement.

You can set the individual speed of the motors (left and then right in the turnForward function), and then we have it pause a bit before returning to full speed.

The code ends when you stop it and cleans up the GPIO port settings before exiting. The code requires the pi2go Python files, which you can grab here: http://4tronix.co.uk/blog/?p=475.

Code listing

Get the code bit.ly/1z1REHW

```
import time, pi2go

pi2go.init()

pi2go.forward(50)

try:
    while True:
      if pi2go.irLeftLine() = True:
         pi2go.turnForward(45, 50)
         time.sleep(2)
         pi2go.forward(50)
         elif pi2go.irRightLine() = True:
         pi2go.turnForward(50, 45)
         time.sleep(2)
         pi2go.forward(50)
    else:
         time.sleep(0.5)

except KeyboardInterrupt:
    print

finally:
    pi2go.cleanup()
```

Hexy the Hexapod

The Kickstarter success story with six legs, 19 servos and some mad dance moves

TECH SPECS

Manufacturer
ArcBotics

Height
100-140 mm

Width and depth
300-400 x 200mm approx (depending on stance)

Weight
0.90 kg

Power
6 or 7.5 volts from 4 or 5 AA batteries

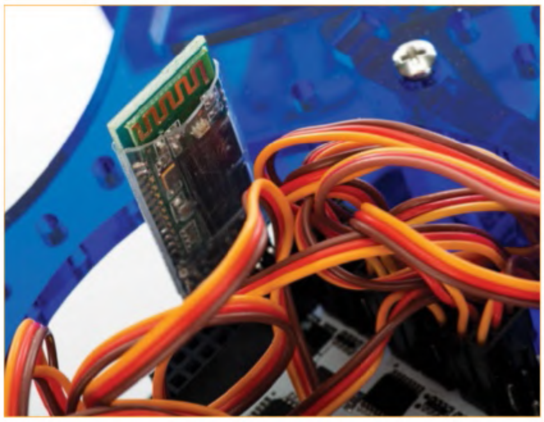
Control board
Arduino

Form of locomotion
Legs x6

Sensors
Ultrasonic sensor

Website
www.arcbotics.com

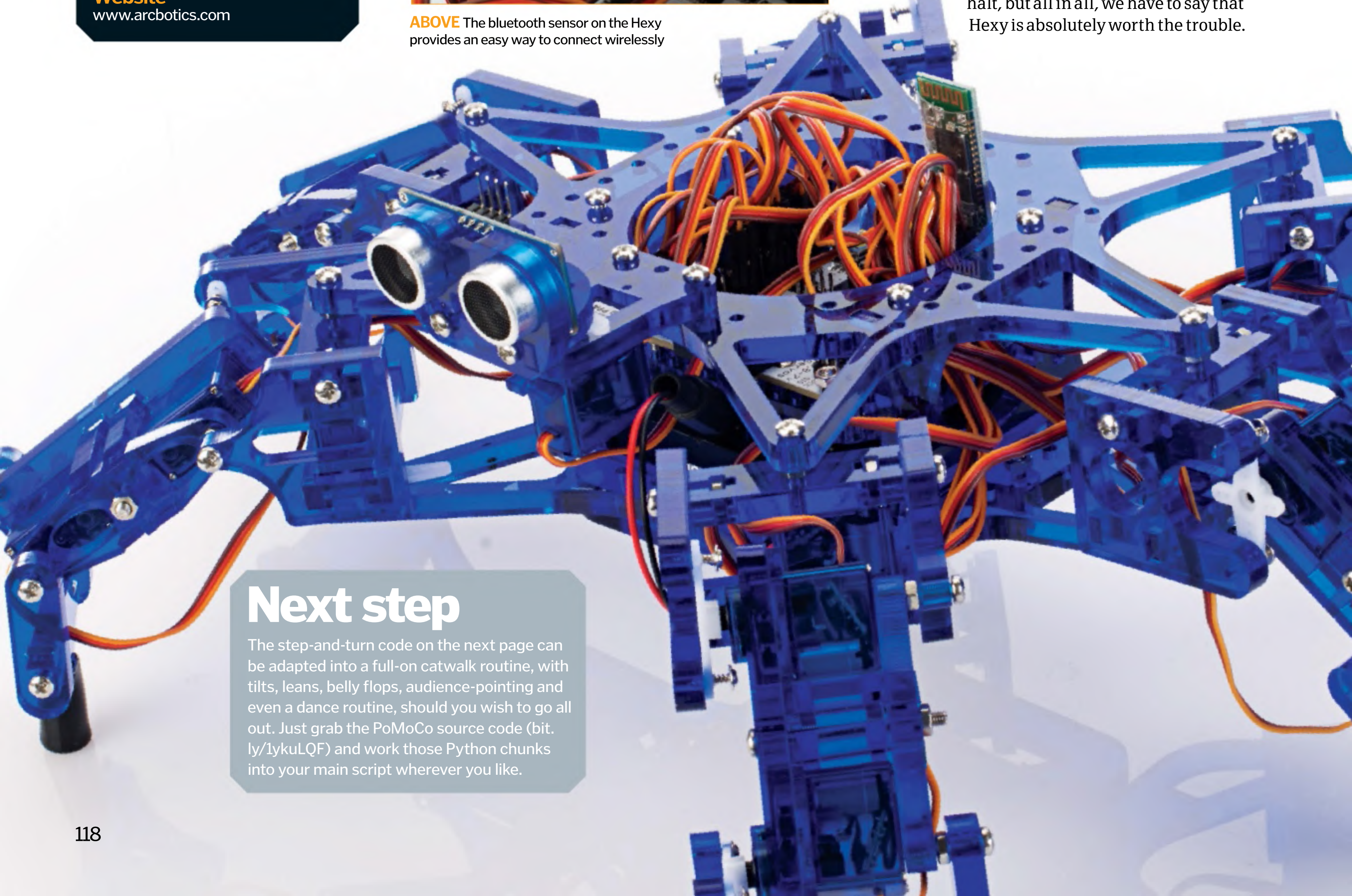
We were really impressed by this all-in-one kit that lives up to its Kickstarter promise of being easy to assemble for people of any skill level, including absolute beginners. Everything is neatly packaged in the box and there's even a tiny screwdriver – meaning you don't need any other tools (though to be fair, those servo horns ended up breaking ours, but more on that later).



ABOVE The bluetooth sensor on the Hexy provides an easy way to connect wirelessly

For the most part the instructions are excellent but there were a couple of occasions where a slight lack of clarity meant that we just followed the images instead, though they were generally spot-on and very useful. You can really see the thought that's gone into it, from the strong and lightweight plastic material to their razor-sharp design. The wiring instructions are perfect and the software tutorials are really useful – you can get an Arduino IDE set up and also dive straight into PoMoCo, ArcBotics' position and motor controller software that's already preloaded with actions (including dance moves) for you to play with.

There's only one real criticism of this kit – the screws are all wrong. There is a big bag of various size screws provided but you don't even use a quarter of them, instead being forced to open each individually packaged servo and borrow the medium screws from them instead because the small holes on the servo horns are far too tiny for the recommended medium screws. The slightly smaller ones from the servo packs fit, so we used those, but you still have to widen those pinholes with brute force. It brings the otherwise speedy build process to a total halt, but all in all, we have to say that Hexy is absolutely worth the trouble.



Next step

The step-and-turn code on the next page can be adapted into a full-on catwalk routine, with tilts, leans, belly flops, audience-pointing and even a dance routine, should you wish to go all out. Just grab the PoMoCo source code (bit.ly/1ykuLQF) and work those Python chunks into your main script wherever you like.

Code listing

```
deg = 25
midFloor = 30
hipSwing = 25
pause = 0.5
rotate_deg = 180
rotate_step = 30
steps = 0
rotations = 0

...

While True:
    if steps != 10:
        # replant tripod2 forward while tripod1
        # move behind
        # relpant tripod 2 forward
        hexy.LF.replantFoot(deg-hipSwing,stepTime=0.5)
        hexy.RM.replantFoot(hipSwing,stepTime=0.5)
        hexy.LB.replantFoot(-deg-hipSwing,stepTime=0.5)

...

else:
        # set neck to where body is turning
        hexy.neck.set(rotate_step)
        # re-plant tripod1 deg degrees forward
        for leg in hexy.tripod1:
            leg.replantFoot(rotate_step,stepTime=0.2)
        time.sleep(0.5)
        # raise tripod2 feet in place as tripod1
        # rotate and neck
        for leg in hexy.tripod2:
             leg.setFootY(int(floor/2.0))
        time.sleep(0.3)
```

Get the code
bit.ly/129HXMK

Three-point turn

Our robots can go in reverse, but how easily can they do a 180 turn?

This is usually a tricky challenge for robots, especially if it has to be done autonomously like in Pi Wars. The challenge requires the robot to walk out of a designated area and travel just over two metres before it performs a three-point turn in an area that is only 750mm deep. Once it has completed this complex manoeuvre, it must then return to the starting area. To do this in the classic way, you'd need to know the speed and distance at which your robot travels with extreme accuracy to make the 180 degree turn easier.

The Hexy has an advantage in that it can literally spin around on the spot, or at least shuffle its way around. There's even example code to make it turn. All you need it to do is walk to the desired location, turn around and walk back. To do this we made a very simple script where the Hexy walks a few 'steps' forward before it attempts a full 180 degree turn and then does the same number of steps back to its starting position. We'll go over some parts of it here but you can grab the full thing through the link we have included next to the code listing above.

First we must define a few basic parameters such as the way in which the Hexy will walk and some of its speed parameters. We've also got a rotation parameter which we have set to 180, but you may need to tweak it for your own Hexy. There's also the steps variable created just to make the code slightly easier.

Next we create a loop where for the first and last ten steps, the legs are articulated in order to make the Hexy move forward. This is a quarter of the 'walk forward' section of the code, and once all parts have been completed we increase the step value by one.

When it has reached ten steps, we do a load of code like in the last part to perform a full 180 degree turn, and then it does ten steps back with another if statement stopping the loop when a further 20 steps have been made.

ABOVE There are three parts to each leg and each part contains one servo. This articulation could potentially enable Hexy to climb over medium-sized objects and obstacles

> "The Hexy has an advantage in that it can spin on the spot"

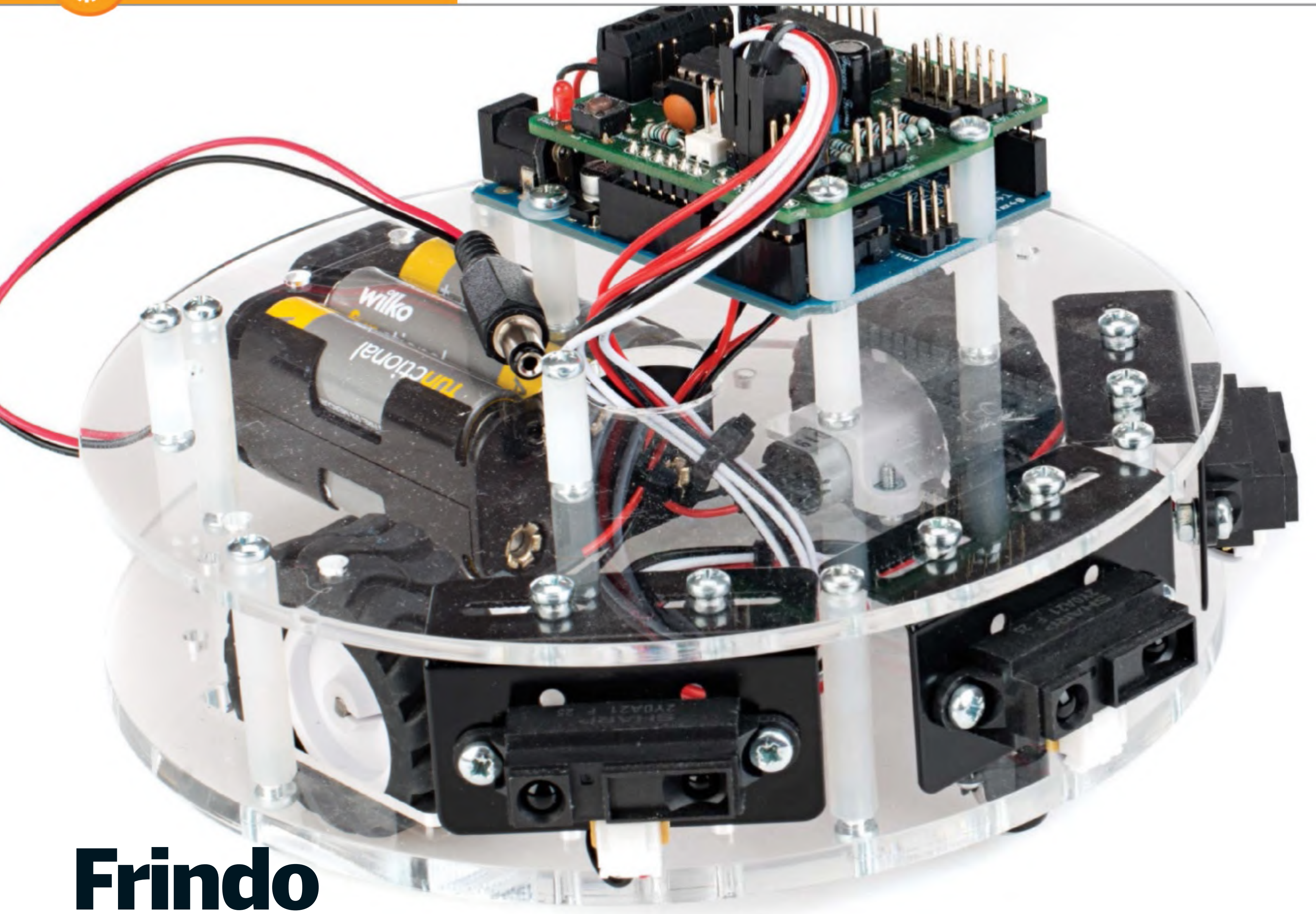
VERDICT

Assembly ★★★☆☆

Build quality ★★★★★

Programmability ★★★★☆

Functionality ★★★★★



Frindo

The puck robot with a low profile and plenty of front-facing sensors

TECH SPECS

Manufacturer
Frindo

Height
85 mm

Width and depth
160 mm diameter

Weight
0.55 kg

Power
9 volts from 6 AA batteries

Control board
Arduino and/or Raspberry Pi

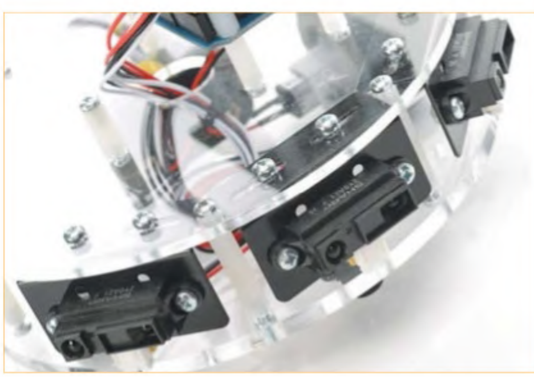
Form of locomotion
Wheels

Sensors
Four infrared proximity sensors

Website
www.robotbits.com

The Frindo is sold more as a robotics platform than an actual all-inclusive robot on its own, but that doesn't mean it's a very basic base to be built upon. Out of the box you can do a fair bit with it, while it's still extremely easy to build upon thanks to its support of standard Arduino and Raspberry Pi boards.

Construction is very straightforward and quick, although you will have to solder on wires to the motor during the construction. This is the only soldering that needs to be done on the Frindo though and it's very basic stuff. However, it is an extra step on top of everything else that not everyone may be equipped for. Still, the actual chassis construction and fitting of the motors and boards and wheels is done with very few components and can be completed quite quickly.



Once it's done you have a few options to upgrade. Firstly, you can add a Raspberry Pi to the system either with or without the supplied Arduino. This can be mounted on the opposite side of the board using holes specifically cut out for the original Model B (though unfortunately not the B+). There's also room for four more proximity sensors as standard, attachable in the spaces between the back and front sensors to create complete 360 degree coverage. The Uno and Pi can take a lot more inputs and outputs as well, so adding custom components is pretty easy.

Due to the dual controller support, the Frindo can be programmed in both Python and the Arduino IDE. Arduino uses the standard libraries and commands, making it great for those already up-to-speed with Arduino programming. The Python program uses the serial library, which uses terminology similar to Arduino, and there's a good, basic example on the website that can help you understand exactly how the sensors and motors can be operated in this fashion.

The Frindo is the most accessible robot we have here. Very simple yet very good, and excellent to learn with plenty of robotic applications.

Code listing

Get the code
bit.ly/121Xa38

```
int frontTrigger = 200;
int sideTrigger = 100;
int rearTrigger = 100;

...

int front_bump() {
            bump = analogRead(FrontBump);
            if(bump > frontTrigger){
                return 1;
                }
            else {
                return 0;
                }
            }

...

void loop() {

            Serial.println("Here we go...");

            while(!front_bump()){
            // while there is no bump keep going forward
            // (about 10cm with GPD120)

                if(!left_bump() && !right_bump()) {
                    Serial.println("NO bump detected - move forward");
                    rs.forward(500, 200);
            // move forward for 500 mS at speed 200
            // (200/255ths of full speed)
                  }

                else if(left_bump() && !right_bump())  {
                    Serial.println("LEFT bump detected - wrong angle");
                    rs.rot_ccw(100, 200);
            // turn right for 100 mS at speed 200
            // (200/255ths of full speed)
                  }

                else if(!left_bump() && right_bump())  {
                    Serial.println("RIGHT bump detected - wrong angle");
                    rs.rot_cw(100, 200);
            // turn left for 100 mS at speed 200
            // (200/255ths of full speed)
                  }

            }
```

Proximity sensor

How close do you dare to go to the wall at the end of the course?

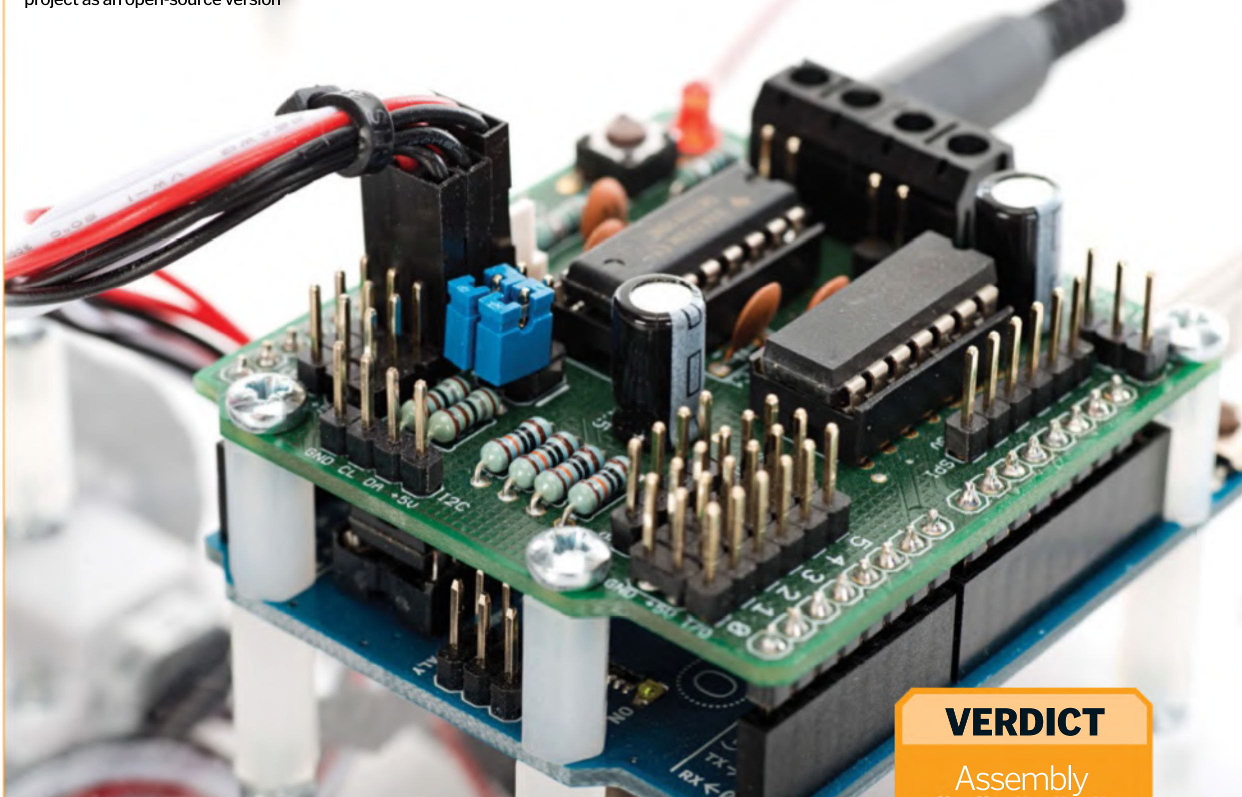
This challenge is somewhat simple: drive right up to a wooden wall and stop before hitting it. The closer you are before coming to a stop, the more points you get. No touching of the wall is allowed. Should be easy with all those proximity sensors, right? Well it's not as easy as you would think, as the proximity sensor is not analogue. Surely there must be a way around this problem though?

The Frindo's sensors have some form of distance sensing on them, although it's by no means perfect. The other thing you'd have to calibrate for is program speed and stopping distance – and that's assuming you're heading straight on to begin with. The motors on the Frindo are unlikely to be in full sync, making it likely that you'll be heaving at a slight angle

That helps us in multiple ways as the Frindo has three sensors on the front, and we can use the left and right sensors to detect the extremes of the wall and turn the Frindo itself to get the perfect stop.

In the code snippets above, you can see that we first define what constitutes the Frindo stopping – this can be modified with trial and error to get a more accurate reading for your situation. The numbers themselves do not correspond to a distance value.

Next is one of the parts where we define how we look at the readings from the sensors so that they can be used in the final part. This rotates the Frindo as it finds any obstacles in its path. The full code for this script can be downloaded using the link above.



BELOW The Robot Shield has been donated to the Frindo project as an open-source version

> "The Frindo's sensors have some form of distance sensing on them"

VERDICT

Assembly

Build quality

Programmability

Functionality

Rapiro

It stood up! The bipedal, humanoid, glowing-eyed, Arduino and Pi-powered robot straight out of Japan

TECH SPECS

Manufacturer
Kiluck

Height
257 mm

Width and depth
196 x 159 mm

Weight
1.00 kg

Power
7.5 volts from 5 AA rechargeable batteries

Control board
Custom Arduino (ATmega 328P) with optional Raspberry Pi

Form of locomotion
Bipedal walking

Sensors
Support for Pi camera

Website
www.rapiro.comcom

The Rapiro is very unique on this list, even when compared to something like the Hexy. We were actually discussing in the office the difference in its design: Rapiro looks like a proper robot with its vacuum-formed shell, which in a way puts form over function. Not that it lacks function, but it's clear its creator Shota Ishiwatari fitted the motors around a design idea rather than design around the functions. It's a bit life-imitating-art, with Rapiro's design referencing robots in Japanese media compared to the hyperfunctional American and British robots with their ultrasonic sensors, line sensors and better stability that are more in line with some Hollywood films out there.

Construction of Rapiro is quite simple; you attach the myriad motors to different parts as you assemble the shell around them and thread the wires into his chest cavity where the Arduino lives. It's not really that fiddly, and there's no soldering or wiring involved. All the motors just plug right into the board using the straightforward labelling you're asked to do in the manual early on.

While the assembly manual is not written by a native English speaker, the repetition and illustrations are generally easy enough to follow along to. Connecting a Raspberry Pi is not covered in the manual, but the Wiki shows where the connections between the Arduino and the Pi should be made, while the mount points are pretty obvious while constructing the head.

Programming the motors and servos are quite easy, with a number of preset serial commands enabling you to create custom scripts for the Rapiro to move or react a certain way to different inputs. This kind of autonomy can be achieved by using the Raspberry Pi and its camera to detect motion or specific objects, or respond to commands sent wirelessly to the board.

It's not the most sophisticated robot on this test, however there's nothing else that can properly walk on two legs either, or grip things. It's unique and useful for different tasks in comparison to the wheeled robots in our selection.

BELOW You can pull off some surprisingly delicate manoeuvres

Robot golf

It's a dog-leg par-four and Rapiro's taking a swing at it

It's actually more of a putting challenge, with the robot tasked to manoeuvre a small ball across a defined space into a goal. The goal is of mouse-hole design, meaning it just needs to be pushed in. While this challenge was envisioned with wheeled robots in mind, we decided we could take it a step further and have the Rapiro knock the ball into the hole with some well-placed swings of a tiny and light gold club. Time is the measure of success, so how would the Rapiro best complete the challenge?

While the Rapiro has superb articulation, it doesn't really have the ability to adopt a traditional golfer stance. Its arms can't cross and it doesn't really bend down. So what we plan to have it to do is hold a golf club and twist its body to hit the ball – very simple, yet effective. Not particularly accurate though, but one step at a time.

You'll see an excerpt of the Arduino script we're using to control the Rapiro, using the test script you can grab. It allows you to set eight movements for the Rapiro to make – this includes the angle of the 12 servos listed in a specific order, the three RGB values of the light and the time the action takes.

In our code, the Rapiro's eyes turn purple (with the mixture of 100 red and 150 blue) and it raises its arm quickly. We have two of the same pieces of code both taking '1' unit of time for this to occur. After that it opens its hand and changes colour to green, allowing you to put a 'golf club' in its hand. It then grips it, turning its eyes yellow to let you know it's getting ready to swing. Finally, it twists its waist to swing the club. Get the full code through the link to the right, but you may have to tweak it to work with your Rapiro.

VERDICT

Assembly

Build quality

Programmability

Functionality

Get the code
bit.ly/1z1REHW

Code listing

```
{  // 10 Golf
  { 90, 90, 90,130, 90,180, 50, 90, 90, 90, 90, 90,100,  0,150,  1},
  { 90, 90, 90,130, 90,180, 50, 90, 90, 90, 90, 90,100,  0,150,  1},
  { 90, 90, 90,130, 90,180, 50, 90, 90, 90, 90, 90,  0,255,  0, 40},
  { 90, 90, 90,130,  0,180, 50, 90, 90, 90, 90, 90,255,255,  0, 10},
  { 90, 90, 90,130,  0,180, 50, 90, 90, 90, 90, 90,255,255,  0, 20},
  { 90,180, 90,130,  0,180, 50, 90, 90, 90, 90, 90,100,  0,150,  1},
  { 90,180, 90,130,  0,180, 50, 90, 90, 90, 90, 90,100,  0,150,  1},
  { 90,180, 90,130,  0,180, 50, 90, 90, 90, 90, 90,100,  0,150,100}
}
```

GoPiGo

The simple and straightforward Pi project robot with WASD control

TECH SPECS

Manufacturer
Kiluck

Height
257 mm

Width and depth
196 x 159 mm

Weight
1.00 kg

Power
7.5 volts from 5 AA rechargeable batteries

Control board
Custom Arduino (ATmega 328P) with optional Raspberry Pi

Form of locomotion
Bipedal walking

Sensors
Support for Pi camera

Website
www.rapiro.comcom

GoPiGo is one of the simplest kits in the array we're testing here – simple in a good way though, with none of the negative connotations. The promised 20-minute build time is no exaggeration and we were up and running with this robot in no time at all. With no soldering required either then this really is an ideal gift for anyone interested in putting their first bot together. Given the sub-$100 (£63.80) price point it also makes an excellent base upon which to build more advanced projects, with plenty of room around the Pi and controller board within the open-sided shield for your own sensors and augmentations.

Straight out of the box, GoPiGo will work with Dexter Industries' firmware to give you WASD control of the two-wheel robot (the ball bearing caster at the rear making this a tricar of sorts), though nothing else beyond basic speed control. Being a Rasperry Pi-based project though, developing more advanced motion scripts and control for things like the optional ultrasonic sensor and camera module is a straightforward task.

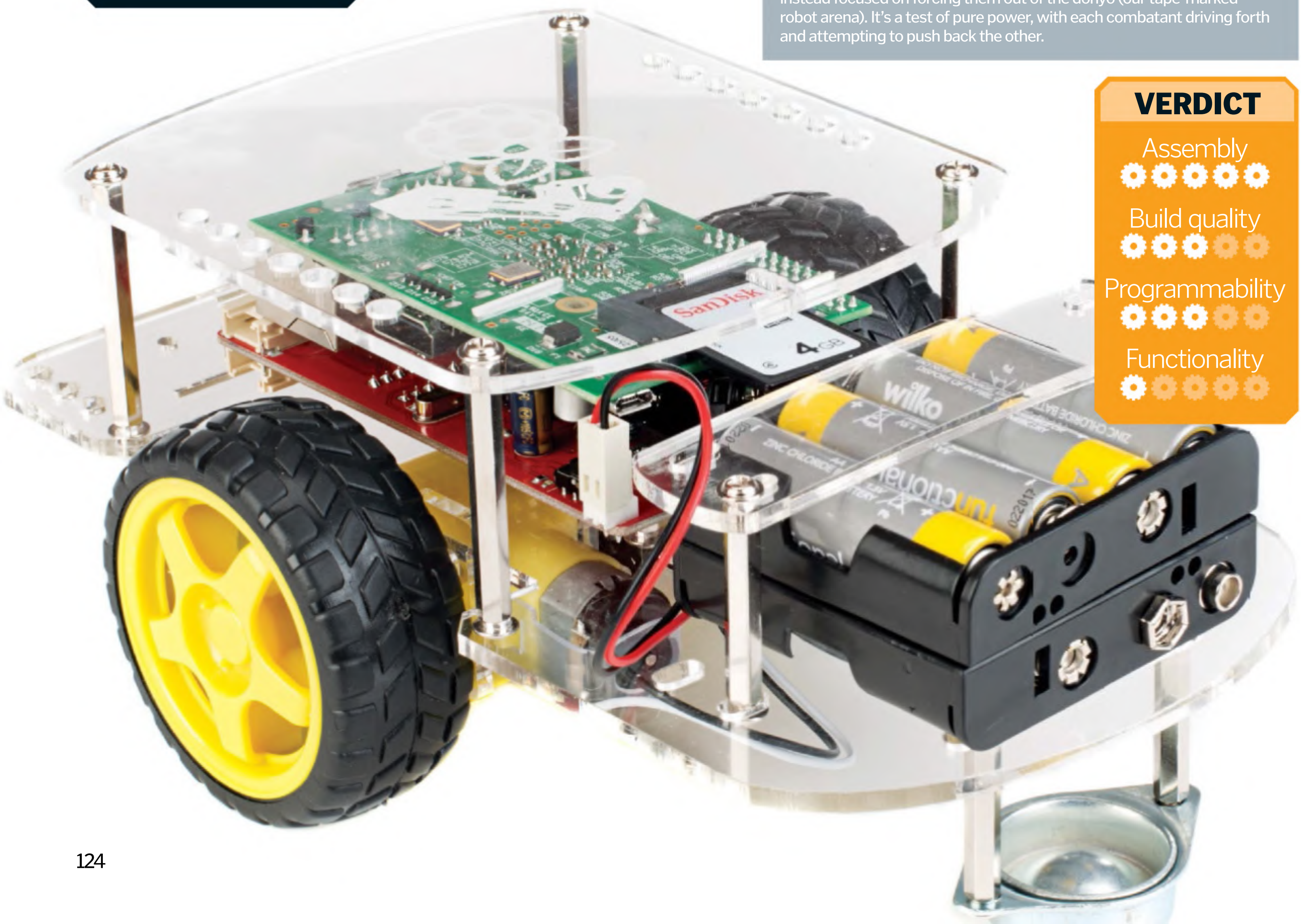
There is one criticism to make, however: it seems there's a flaw with the design in that we found it impossible to connect the wheels properly. The wheels themselves simply slip onto the end of the axles, and can very easily be popped off with a quick knock. The short axle length and nuts that graze the inner tyre wheels mean that it's difficult to actually push the wheels far enough onto the axles to give you the confidence that it'll all hold together while driving.

But that aside, and given the otherwise sterling quality of the GoPiGo robot, we still feel that this is definitely one of our favourite kits.

> "We were up and running with this robot in no time – and no soldering"

Sumo battle

Our 'gentle robots of strength' tested their torque in the fine tradition of sumo wrestling. The rules were simple, though slightly different to those of the more well-known Homo sapiens variant of this popular robosport. Matches could not be won by forcing the opposing automaton to touch the ground with any part of their body other than the soles of their feet – largely because this would be impossible in most cases – but were instead focused on forcing them out of the dohyo (our tape-marked robot arena). It's a test of pure power, with each combatant driving forth and attempting to push back the other.



VERDICT

Assembly

Build quality

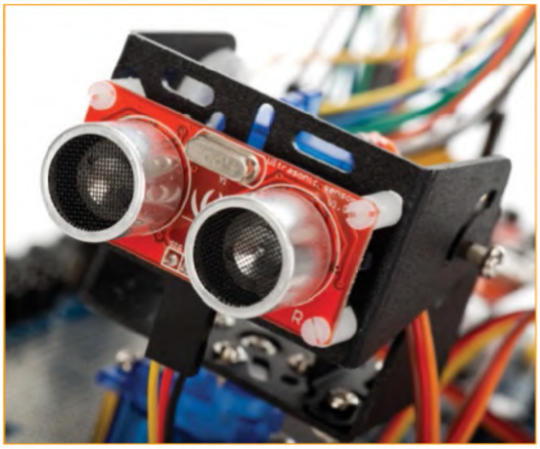
Programmability

Functionality

Scores explained

Here's a breakdown of our verdicts on these robots' qualities and capabilities

Rover5



Assembly
A little tricky in practise but still quite solid. **3**/5

Build quality
Generally fine but some of the screws are a little cheap. **4**/5

Programmability
For those without Arduino experience it can be a little confusing. **3**/5

Functionality
Great traction, great control and aware of its surroundings. **5**/5

Rapiro

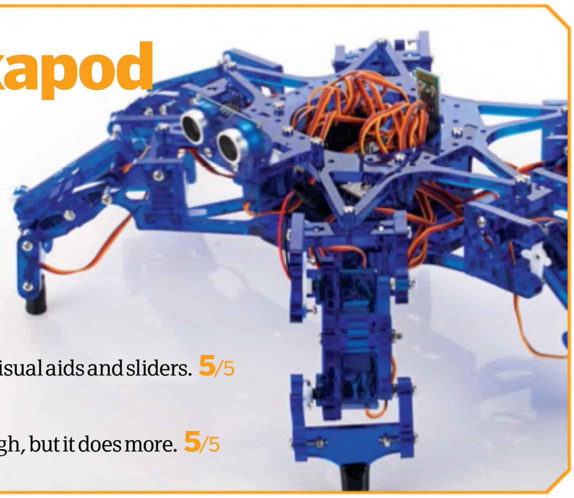
Assembly
Time-consuming but not fiddly due to its size. **4**/5

Build quality
It's very sturdy with a low centre of gravity. **5**/5

Programmability
Very simplistic Arduino commands are available. **3**/5

Functionality
Rapiro can move by your commands and that's about it. **2**/5

Hexy the Hexapod



Assembly
Fairly straightforward, but the wide array of screws doesn't help. **3**/5

Build quality
Generally quite solid, but not consistent due to the screws. **4**/5

Programmability
PoMoCo gives full control over Hexy using visual aids and sliders. **5**/5

Functionality
Movement capabilities are incredible enough, but it does more. **5**/5

Pi2Go

Assembly
Soldering the kit together is time-consuming and not easy. **3**/5

Build quality
It's stable, but the chassis is its circuit boards. **3**/5

Programmability
A custom Python library makes it fairly easy to program. **4**/5

Functionality
For its size and price it has an absurd amount of features. **5**/5

GoPiGo

Assembly
Simple and quick construction takes less than half an hour. **5**/5

Build quality
Generally okay, but the wheels have a problem staying on. **3**/5

Programmability
Can use simple terminal commands and be fully programmed. **3**/5

Functionality
GoPiGo can move on its wheels, but it has no sensors built-in. **1**/5

Frindo

Assembly
Simple and quick; the basic chassis is easily constructed. **4**/5

Build quality
Very sturdy due to its shape and all components are protected. **4**/5

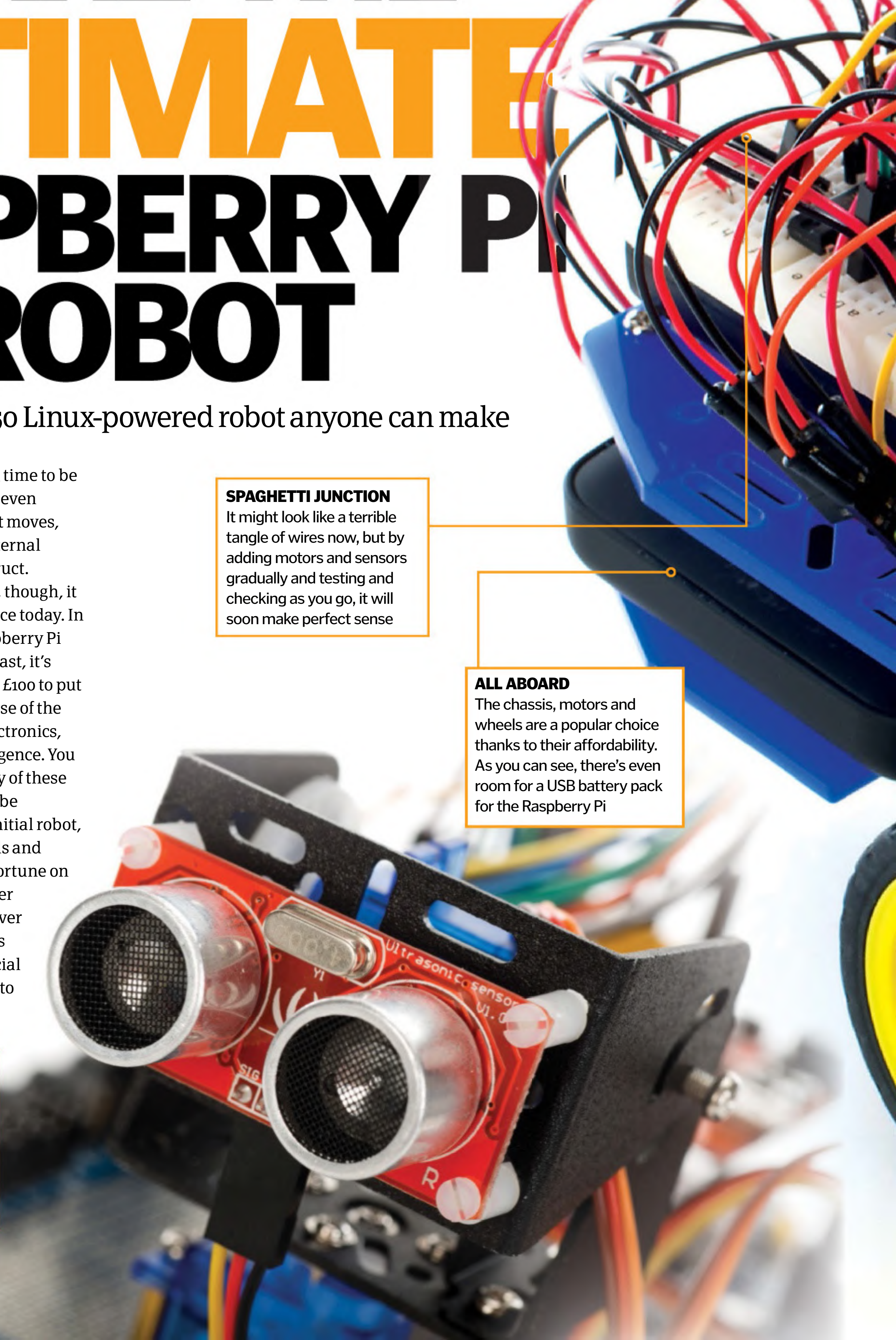
Programmability
If Arduino isn't your thing, you can always code it in Python. **4**/5

Functionality
The Frindo comes with three sensors but can be upgraded. **4**/5

MAKE THE ULTIMATE RASPBERRY PI ROBOT

Say hello to the £150 Linux-powered robot anyone can make

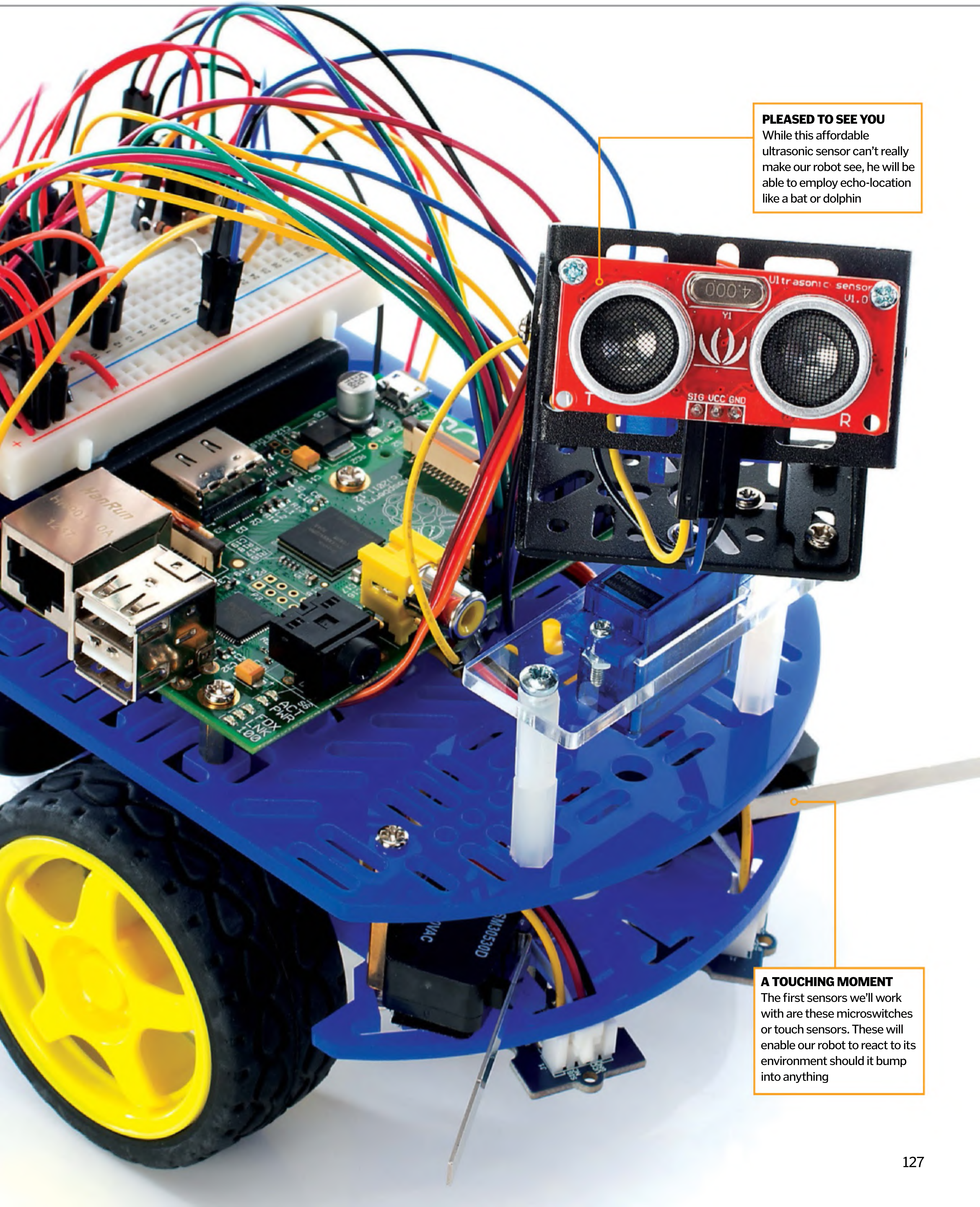
There's never been a more exciting time to be into robotics. Until more recently even building the most basic robot that moves, senses its environment and reacts to external stimuli cost thousands of pounds construct. Thanks to devices like the Raspberry Pi, though, it can be done at a mere fraction of that price today. In fact, assuming you've already got a Raspberry Pi and have dabbled in electronics in the past, it's unlikely you'll need to spend more than £100 to put our project robot together. Over the course of the feature we'll be exploring aspects of electronics, programming and basic artificial intelligence. You don't need to have any experience in any of these fascinating fields, but we do hope you'll be inspired to learn. We'll be making the initial robot, and will then go on to give him new skills and abilities, but you don't need to spend a fortune on sensors and actuators to do real computer science. Just by following our progress over the next pages, the door to exciting fields like navigation, maze solving and artificial intelligence will already be firmly open to you and your amazing robot creation.



SPAGHETTI JUNCTION
It might look like a terrible tangle of wires now, but by adding motors and sensors gradually and testing and checking as you go, it will soon make perfect sense

ALL ABOARD
The chassis, motors and wheels are a popular choice thanks to their affordability. As you can see, there's even room for a USB battery pack for the Raspberry Pi

CAUTION
While we've carefully constructed this feature with safety in mind, accidents can happen. Imagine Publishing cannot be held responsible for damage caused to Raspberry Pis and associated hardware by following this feature.



PLEASED TO SEE YOU
While this affordable ultrasonic sensor can't really make our robot see, he will be able to employ echo-location like a bat or dolphin

A TOUCHING MOMENT
The first sensors we'll work with are these microswitches or touch sensors. These will enable our robot to react to its environment should it bump into anything

EVERYTHING YOU'LL NEED

Get off on the right foot with the right tools, parts and know-how

With our help you'll find that building a robot with a Raspberry Pi isn't as hard or expensive as you might think. Since there are a number of technical challenges to overcome, you'll need a good selection of electronic prototyping bits and bobs, specialist chips and a few tools to help along the way.

We've laid out many of the core components we've used to make our Raspberry Pi robot below. Don't feel limited to our choices, though. As you'll quickly learn as we make our way through this ambitious project, you can apply the core skills (and even code) needed to access and control the technology to just about any digital or analogue sensors.

Make sure you have a decent small-headed Phillips screwdriver, some decent wire cutters and a soldering iron to hand. While there is very little soldering involved in the initial build, many of the sensors and actuators you'll need later on will depend on them.

If you're looking for the right kit, with the best service at the most competitive prices, you could spend weeks canvassing companies or reading online reviews. Or, you could simply rely on the suppliers we used to put our kit together...

MODMYPI
www.modmypi.com
We relied heavily on Modmypi's extensive range of hacking and prototyping bits and bobs like breadboards, resistor kits and jumper wires

DAWN ROBOTICS
www.dawnrobotics.co.uk
Dawn Robotics' Alan Braun knows robots. That's why we relied on his services for the Magician chassis and the ultrasonic sensor among other things

PIMORONI
shop.pimoroni.com
If you're looking for the best cases, cables and accessories, Pimoroni is essential and they have a great range of sensors too

CPC
cpc.farnell.com
We got our Raspberry Pi, microswitches and some of our tools from CPC. They have a mind-boggling range and the buying power to offer brilliant prices

MAKE AND RUN PYTHON CODE

You can use whatever development environment you're most comfortable with to write your Python code, be that IDLE, Geany or anything else. That said, there's a lot to be said for simply opening LeafPad, typing some code and saving it as a .py file. It's quicker, more convenient and if you'll learning to code, you'll thank us later.

When it comes to running your scripts or our examples, you need to use elevated privileges or your code can't interact with the GPIO pins. This being the case, simply navigate to your file in the terminal and type:

`sudo python file.py` (where 'file' is the name of your code document).

EASY ACCESS WITH SSH

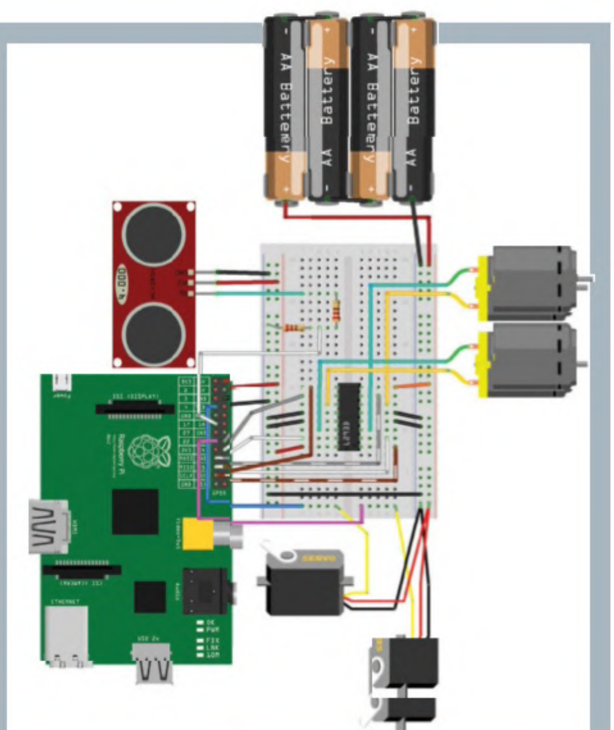
For the ultimate Raspberry Pi robot coding experience we highly recommend kitting out your Pi with a Wi-Fi dongle and SSHing into your Pi from a separate Linux computer. All it requires is that you know the IP address of your Raspberry Pi. You can find it simply by opening a terminal (once you are connected via Wi-Fi) and typing: `ifconfig`

Look for the output that relates to Wi-Fi and make a note of the IP address number. Now open a terminal window on your other computer and type `ssh pi@xxx.xxx.x.xxx`

...using the IP address you wrote down a moment ago. If you've changed the default name from 'pi', don't forget to update that too.

Once you've input your Pi's password (the default is 'raspberry') you'll be connected to your Pi. From here you can navigate to your Python scripts and execute them the usual way. You can even type: `nano file.py`

...to edit your files before running using nano.



Usually there are two options when you're demonstrating electronics – complex circuit diagrams or hard-to-read breadboard photography. Luckily for us there's a third option, which combines the best of both worlds: Fritzing.

Fritzing is an open source project designed to support anyone who works with electronics. The tool allows you to pick components and – using a drag-and-drop interface – simply place them on a document and then output it as an image. Hopefully you'll have as much fun using Fritzing with your projects as we did with this one! **www.fritzing.org**

WORKING WITH THE GPIO PORT

Get to know the GPIO pins on your Raspberry Pi – you won't get far without them

The general-purpose input/output (GPIO) pins on your Raspberry Pi are central to the success of a project such as this. Without them we have no way of interfacing with our motors, sensors or actuators.

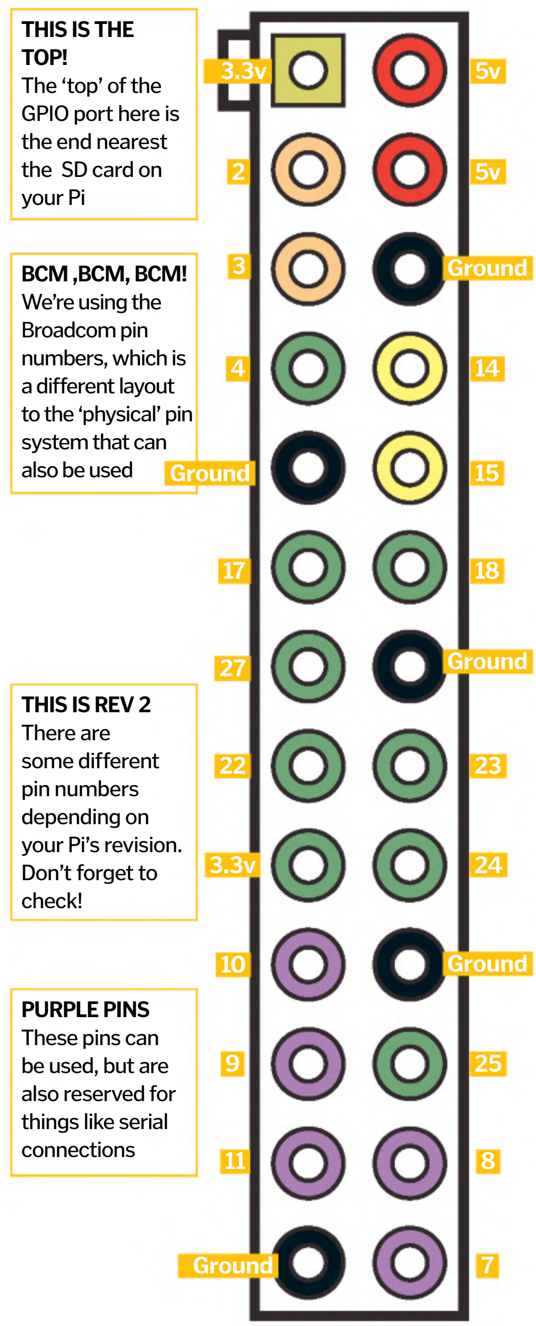
As you'll soon see, with the help of the Raspberry Pi GPIO Python library it's actually very easy to use them provided you're using the right pin for the right job. Finding the right pin is more challenging that you might think, though, since the pins themselves can actually have several names. For example, GPIO 18 is also pin 12 and PCM_CLK. To save as much confusion as possible, we're using the Broadcom naming convention, as opposed to the board convention. Therefore, in our code you'll see `GPIO.setmode(GPIO.BCM)`

...in all our code listings.

To make matters worse, some pin numbers also changed between Revision 1 and Revision 2 boards.

We're using Revision 2 in this diagram (the Raspberry Pi with 512MB of RAM and mounting holes), but you can find the Revision 1 version by searching for 'Raspberry Pi GPIO' online.

It can be confusing at first, but the easiest way to deal with the GPIO pins is to pick a convention and stick with it!



> *"We highly recommend kitting out your Pi with a Wi-Fi dongle and SSHing into your Pi"*

Build the motor circuit

Let's start by making a simple motor circuit on the Raspberry Pi

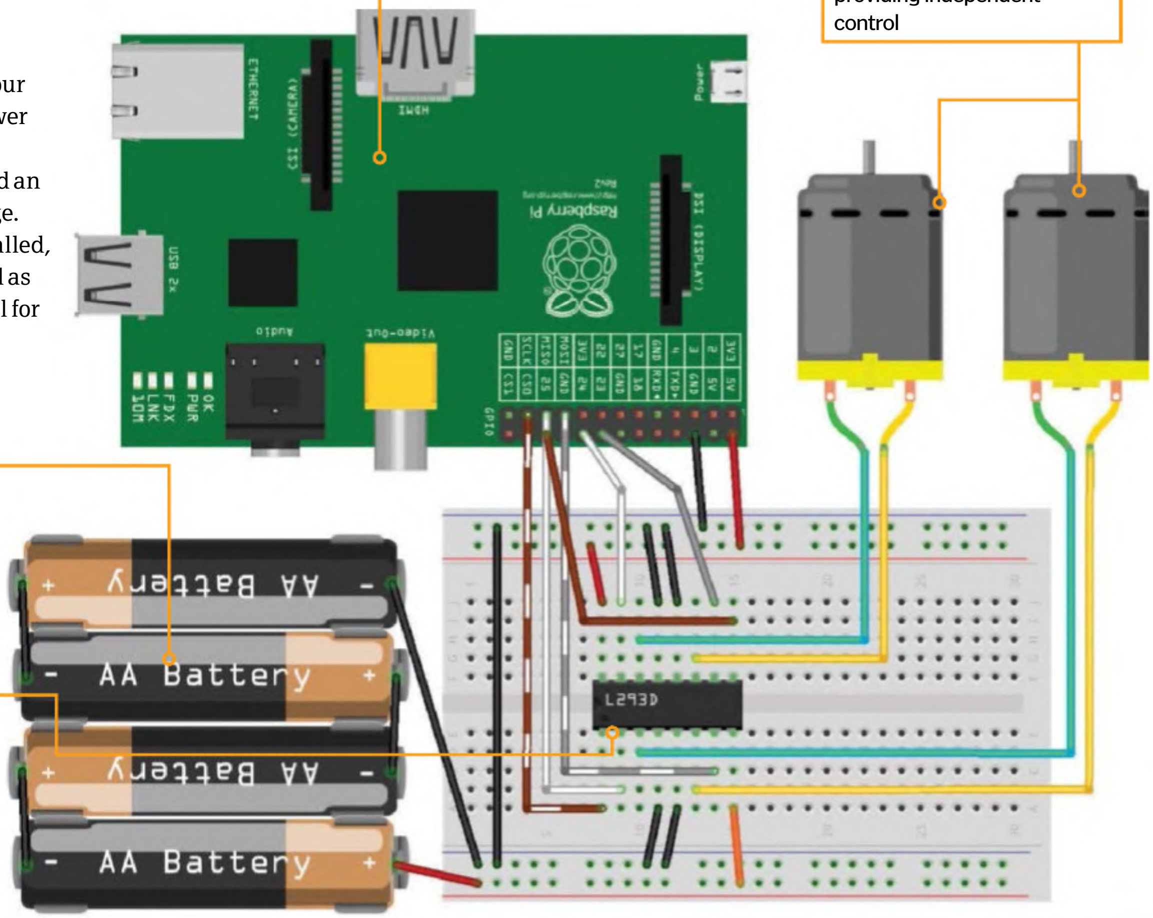
The base skill of our robot is movement, and this is handled by the motors supplied with our Magician chassis. Motors come in a large variety of shapes and sizes, types and models, but here we will safely connect two DC motors to the Raspberry Pi.

Due to the limited electrical power offered by the Pi, we will require some additional batteries a small IC to turn our motors on and off for us. Don't ever power them from the Pi.

The motor driver we will use is called an L293D, otherwise known as an H-Bridge. This one IC, or chip as it's sometimes called, will handle the separate power control as well as providing bi-directional control for two motors.

RASPBERRY PI
Works with both rev 1 and rev 2 model B, and model A Raspberry Pis

MULTIPLE MOTORS
The single motor driver can handle 2 separate DC motors, providing independent control



ADDITIONAL POWER
Motors are powered by four AA batteries giving us 6 volts, perfect for most small robots

MOTOR DRIVER
The L293D sitting across the middle of the breadboard will perform all the hard work

Parts list

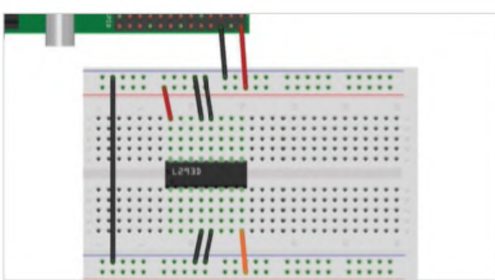
- Raspberry Pi (any model)
- Breadboard
- 2x DC motors
- L293D IC
- Jumper wires
- 4x AA batteries
- Battery holder

CAUTION
NEVER connect motors directly to your Raspberry Pi. Doing so can damage the central processor, resulting in a costly (but attractive) paperweight.

01 Adding the L293D

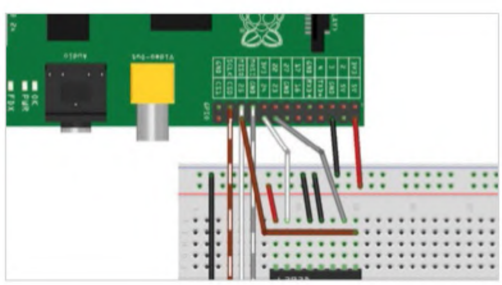
Place the L293D chip into the middle of the breadboard and add the red and black power cables, paying attention to the pins.

The orange wire will be for the batteries.



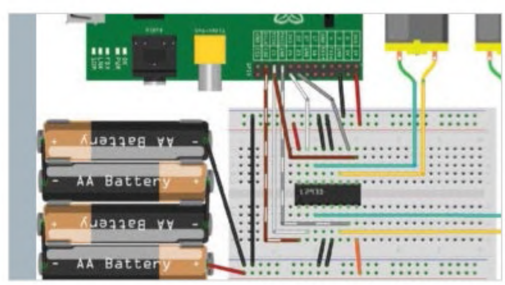
02 Configure the data lines

Double-check the connections to ensure the pins are correct. There are six wires going from the Pi GPIO pins to the input pins of the L293D. These will be responsible for our motors.



03 Finish the circuit

Now we can add the motors. We won't know which way they will turn yet, so make sure you can easily swap them around. Finally, add the batteries and plug in the Raspberry Pi.



First motor test

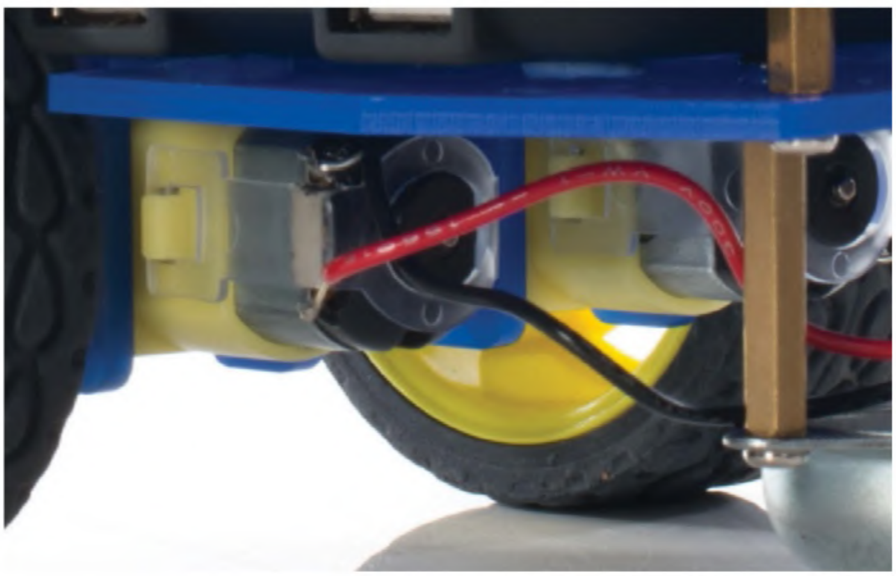
With your circuit complete, here is how to get your motors moving

Using Python to control the motors is made nice and simple with a library called RPi.GPIO. This gets imported into your script and will handle all the turning on and off that you require. It can also take inputs such as sensors and switches that we shall cover over the next few pages, but first let's make our motors turn to give us some movement.

First we'll import the library we need, RPi.GPIO. We also want to be able to pause the script so we can let the action run, so we'll need to also import the sleep function from the library called time. Next we'll tell the script what numbering we require. The Raspberry Pi has two numbering schemes for the GPIO pins: 'board' corresponds to the physical location of the pins, and 'BCM' is the processors' numbering scheme. In these scripts we'll use the BCM scheme.

It's not necessary, but it's a good idea (to save on confusion later) to give the pins you will use a name. So we shall use the L293D pin names to make controlling them easier. Each motor requires three pins: an A and a B to control the direction, and Enable that will work as an on/off switch. We can also use PWM on the Enable pin to control the speed of the motors, which we shall look at after this.

All that leaves us with is to tell the pins they need to be an output, since we are sending our signal from the Raspberry Pi. To turn the pin on – otherwise known as 1, or HIGH – we tell the Raspberry Pi to set that pin high; and likewise, to turn it off, we set the pin LOW. Once we have set the pins, we shall pause the script using time.sleep() to give the motors a few seconds to run before changing their direction.



Motor circuit code listing

Get the code: http://bit.ly/1iNYbTQ

```
import RPi.GPIO as GPIO
from time import sleep

GPIO.setmode(GPIO.BCM)
```

THE START
These are the GPIO pin numbers we're using for our motors. We've named them according to the L293D for clarity

```
Motor1A = 24
Motor1B = 23
Motor1E = 25

Motor2A = 9
Motor2B = 10
Motor2E = 11
```

SETTING OUTPUTS
As we want the motors to do something, we need to tell Python it is an output, not an input

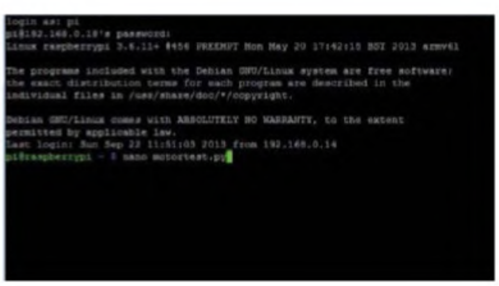
```
GPIO.setup(Motor1A,GPIO.OUT)
GPIO.setup(Motor1B,GPIO.OUT)
GPIO.setup(Motor1E,GPIO.OUT)

GPIO.setup(Motor2A,GPIO.OUT)
GPIO.setup(Motor2B,GPIO.OUT)
GPIO.setup(Motor2E,GPIO.OUT)
```

MAKING MOVEMENT
We are now telling the L293D which pins should be on to create movement – forwards, backwards and also stopping

```
print "Going forwards"
GPIO.output(Motor1A,GPIO.HIGH)
GPIO.output(Motor1B,GPIO.LOW)
GPIO.output(Motor1E,GPIO.HIGH)

GPIO.output(Motor2A,GPIO.HIGH)
GPIO.output(Motor2B,GPIO.LOW)
GPIO.output(Motor2E,GPIO.HIGH)

print "... for 2 seconds."
sleep(2)

print "Going backwards"
GPIO.output(Motor1A,GPIO.LOW)
GPIO.output(Motor1B,GPIO.HIGH)
GPIO.output(Motor1E,GPIO.HIGH)

GPIO.output(Motor2A,GPIO.LOW)
GPIO.output(Motor2B,GPIO.HIGH)
GPIO.output(Motor2E,GPIO.HIGH)

print "... for 2 seconds"
sleep(2)

print "And stop before cleaning up"
GPIO.output(Motor1E,GPIO.LOW)
GPIO.output(Motor2E,GPIO.LOW)

GPIO.cleanup()
```

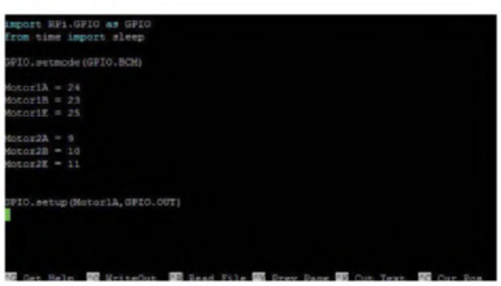
04 Prepare your script

Login into your Raspberry Pi – username is 'pi' and password is 'raspberry'. Now we'll create our first script, type in `nano motortest.py` to begin. This will open the nano text editor.



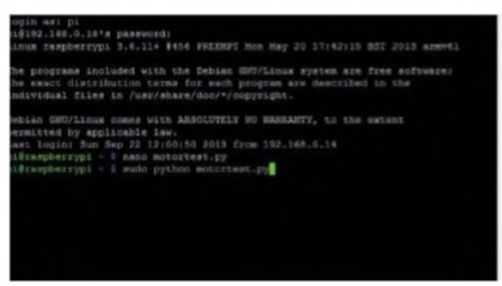
05 Save your code

Typing the code, but remember it's case sensitive. Capital letters are important. And indent the code with a space, keeping it consistent. When done, hold Ctrl and press X, then Y to save.



06 Test your motors

Now to run it. For this we type: `sudo python motortest.py`. If something doesn't work, retrace the wires, making sure they connect to the right pins and that the batteries are fresh.



Assemble the robot chassis

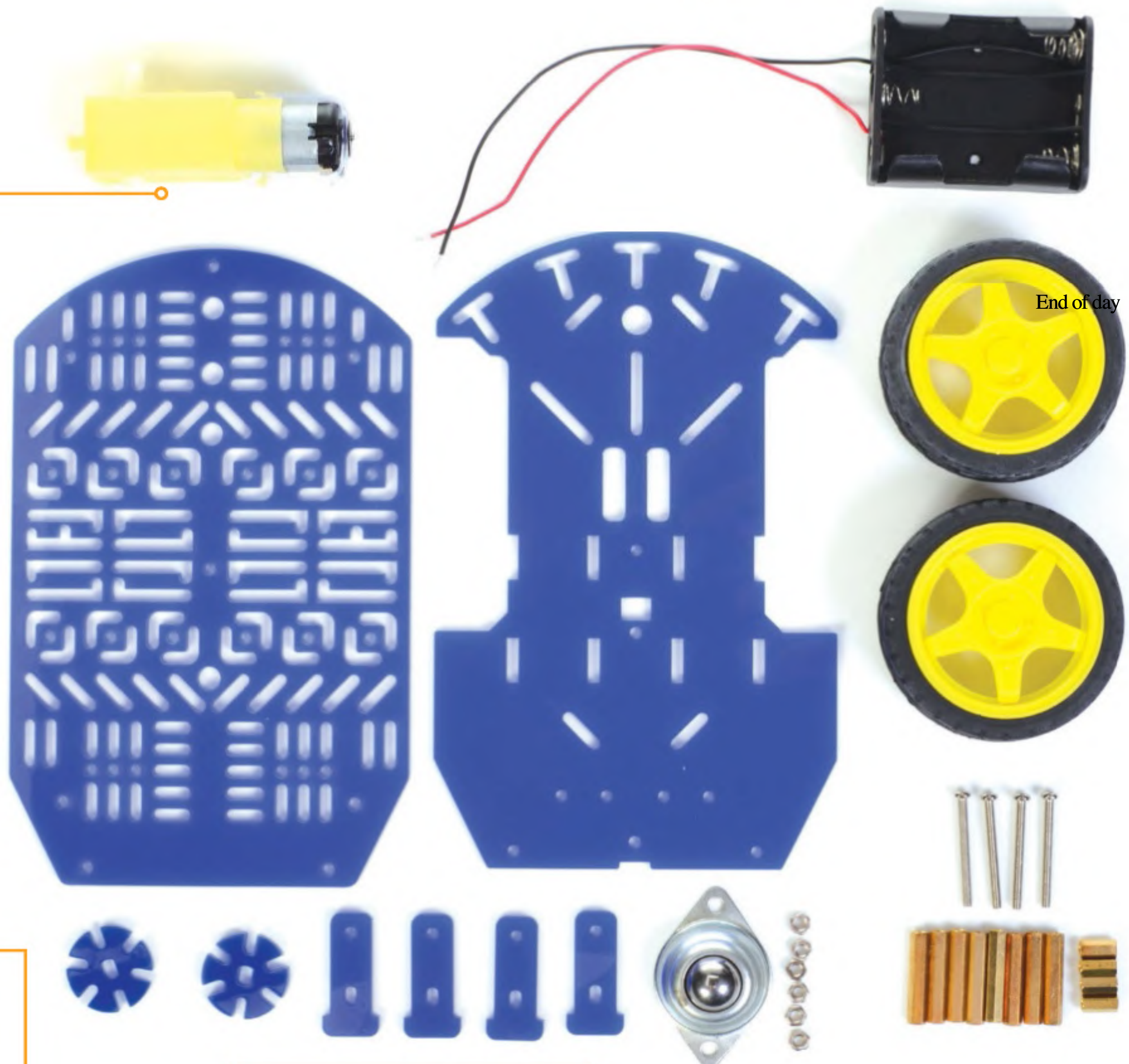
Now we've got a working motor circuit, let's start building our Raspberry Pi robot

One thing a robot can't live without is somewhere to mount all the parts, so for this we need a chassis. There are many different sizes, shapes and finishes available. We are going to use one of the most versatile and common, called a Dagu Magician.

This chassis kit comes complete with two mounting plates, two motors and two wheels, as well as a battery box, which is perfect as a starting point for most basic robots. Once this is ready, we can start to expand our robot with new motor functions, before adding sensors.

01 SORT THROUGH THE PARTS
Lay all the parts out and familiarise yourself with them. Assembly is for the most part straightforward; some care is needed with the motor bracket, though.

02 ASSEMBLE THE MOTOR BRACKET
Insert the bracket through the chassis and sandwich a motor with the second bracket. Feed a bolt through the holes and add the nut on the end.



03 PIECE THE BITS TOGETHER
Feed the motor wires up through the chassis and add the top plate using the hexagonal spacers and screws, followed by the castor.

04 WIRE EVERYTHING UP
With everything in place, using the motor circuit, reconnect the Raspberry Pi again and switch it on. Make sure it works by running the test script.

05 ADD THE BREADBOARD
Most breadboards have an adhesive pad on the bottom so you can peel and stick down or use Blu-tack for a less permanent fix. Mount this at the front.

06 MOUNT YOUR PI
The Raspberry Pi rev 2 and some cases have mounting holes on the bottom, so utilise them for mounting, and fix the battery packs into place.

Building tips

Take your time
It's easy to jump ahead and assume you already understand the build process without glancing at the instructions. That pamphlet is there to help – use it!

Modifications are welcome
Don't limit yourself to the stock design. If you need to cut a new set of holes for your sensors, measure twice and cut once, but don't feel limited to the stock options.

Plenty of choice
There is a world of choice when it comes to robot platforms. Four wheels, tracks and even hexapods are possible. Take a look at the robots we tested on pages 112-125 for more ideas.

Create movement functions in Python

Our simple motor test won't do for a finished robot – we need to add more abilities, so let's add some movement functions we can call upon whenever we want

Now that we have a fantastic-looking robot and everything wired in the right place (apart from the motors, which we may have to change), we can plug in the Raspberry Pi and write our first script to make the robot controllable. Our simple motor test from before was perfect for checking if the motors worked and gave us the basics of movement, but we want to be able to control and move it around properly and with precision. To do this we need to create our own functions.

In Python this is done easily by grouping repetitive actions into a definition or def block. Using the def block we can pass parameters such as speed easily, and write the code that controls the pins with ease. We will also add PWM support, so we can set a speed that the motors should run at.

In the first few blocks of code, we'll set up the pins we need, setting them as outputs; the next block tells Python to enable PWM on the two Enable pins.

In the next few blocks we are starting to create our functions, giving them easy-to-remember names such as forward and backward, but also allowing individual motor controls by using left and right.

Up to this point nothing will happen, as we haven't told Python what we want to do with them – we do that at the end. We shall tell the motors to go forward at 100 (which is full power) for three seconds, then backwards at full power for three seconds.

01 Set the pins

To begin with, we'll import the classes we need, and set up the pins the same as we did for the motor test.

```
import RPi.GPIO as GPIO
from time import sleep

GPIO.setmode(GPIO.BCM)

GPIO.setup(24,GPIO.OUT)
GPIO.setup(23,GPIO.OUT)
GPIO.setup(25,GPIO.OUT)
GPIO.setup(9,GPIO.OUT)
GPIO.setup(10,GPIO.OUT)
GPIO.setup(11,GPIO.OUT)
```

02 Enable PWM support

To allow us to control the speed of the motors, we require pulse-width modulation (PWM). As the Enable pin supports this and works for both directions, we'll set it to this pin.

```
Motor1 = GPIO.PWM(25, 50)
Motor1.start(0)
Motor2 = GPIO.PWM(11, 50)
Motor2.start(0)
```

03 Create movement functions

Python allows us to simplify and reuse code, making it shorter and easier to read. We'll use this to save typing which pin needs to do what, by grouping them into a definition block.

```
def forward(speed):
  GPIO.output(24,GPIO.HIGH)
  GPIO.output(23,GPIO.LOW)
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor1.ChangeDutyCycle(speed)
  Motor2.ChangeDutyCycle(speed)
```

04 How to change speed

With the addition of the **(speed)** element, we can input a number into the function that it can use and return the result – in our case, the speed of the motor – back into the script.

```
def backward(speed):
  GPIO.output(24,GPIO.LOW)
  GPIO.output(23,GPIO.HIGH)
  GPIO.output(9,GPIO.LOW)
  GPIO.output(10,GPIO.HIGH)
  Motor1.ChangeDutyCycle(speed)
  Motor2.ChangeDutyCycle(speed)

def left(speed):
  GPIO.output(24,GPIO.HIGH)
  GPIO.output(23,GPIO.LOW)
  Motor1.ChangeDutyCycle(speed)

def right(speed):
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor2.ChangeDutyCycle(speed)

def stop():
  Motor1.ChangeDutyCycle(0)
  Motor2.ChangeDutyCycle(0)
```

05 Make it move

Up until now the script will do nothing noticeable, but all the hard work is now out of the way. To give it some movement, we shall use our new variables.

```
forward(100)
sleep(3)
backward(100)
sleep(3)
forward(50)
sleep(5)
stop()
left(75)
sleep(2)
right(75)
sleep(2)
stop()
```

PULSE-WIDTH MODULATION

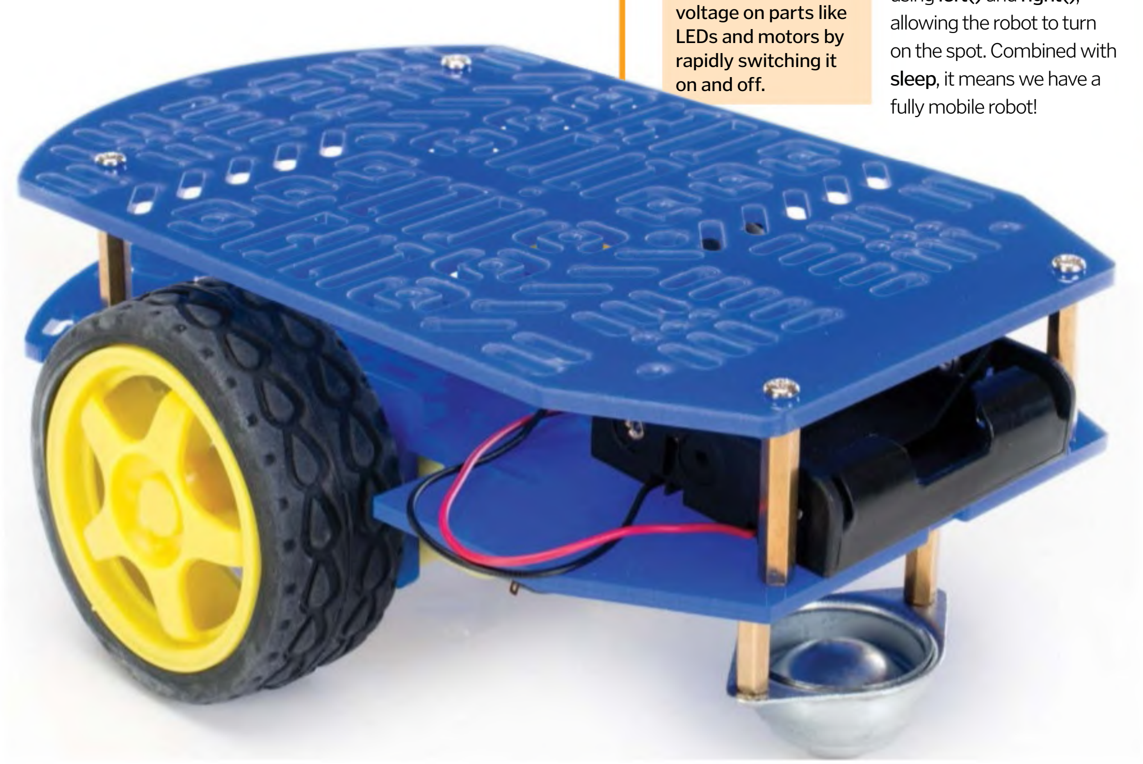
PWM is a technique used to vary the voltage on parts like LEDs and motors by rapidly switching it on and off.

06 Individual movements

We are also able to control each motor separately by using **left()** and **right()**, allowing the robot to turn on the spot. Combined with **sleep**, it means we have a fully mobile robot!

REPEATING CODE

In Python we use a definition block to repeat sections of code; this allows us to use the same code several times, as well as making changes quickly.



"We want to be able to control and move it around with precision"

Installing microswitches

Give your robot the sense of touch and train it to react when it bumps into something

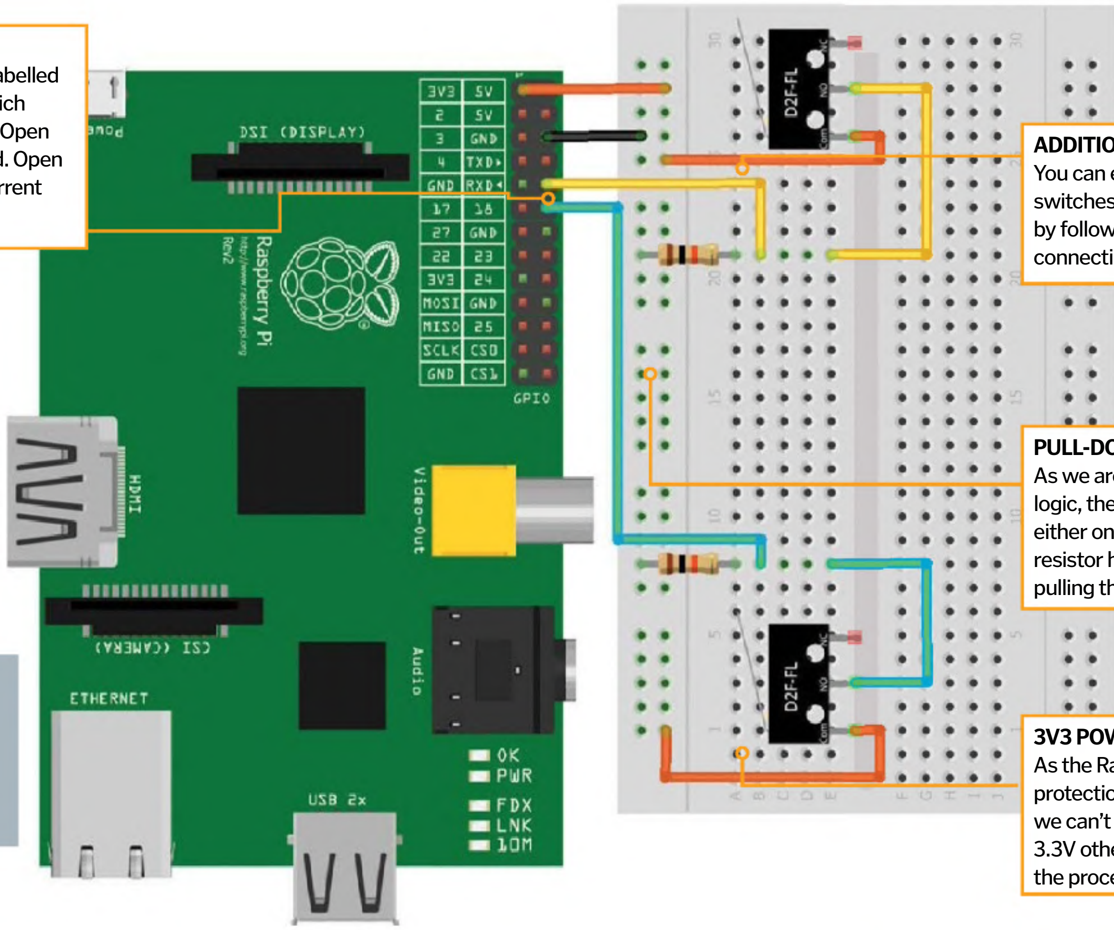
Now we've got a robot that can move anyway we want it to, let's move on to the simplest form of interaction: touch.

For our Raspberry Pi robot, it may not be as sophisticated as we experience as humans, but giving our robot its first sense will help it to navigate its own path, giving it a very basic form of intelligence.

Adding a sense of touch can be handled in different ways, but the quickest and easiest method is by adding some 'antennae' to your robot in the form of microswitches. Given their name, they aren't so much micro but they have long arms that protrude, making them perfect for mounting on the front of the robot. If your switch hasn't got a lever or it isn't long enough, you can always try adding or extending it using a piece of dowel or a drinking straw.

Adding multiple switches gives our robot a greater sense of its surroundings and allows a very simple bit of code to control how it should operate. As it will be moving forward, we will only need to add switches to the front. So let's begin by creating the circuit and testing it.

NO/NC
Most switches are labelled with NO and NC; which stands for Normally Open and Normally Closed. Open simply means no current can pass through



ADDITIONAL SWITCHES
You can easily add more switches, not just bumpers, by following the circuit and connecting it to a free pin

PULL-DOWN RESISTORS
As we are dealing with digital logic, the switch has to be either on or off, and the resistor helps this by weakly pulling the pin low

3V3 POWER
As the Raspberry Pi has no protection from overvoltage, we can't input more than 3.3V otherwise we risk frying the processor

Parts list
- Jumper wires
- 2x 10K resistors
- 2x CPC microswitches

Testing your microswitches

Now the switches are wired up, let's get them working

Wiring them up is nice and simple, but as mentioned, it is important to remember that the Raspberry Pi is only 3.3V tolerant when using inputs, so we are only going to use the 3V3 pin and NOT the 5V pin.

The Python code to read inputs is nice and straightforward. Since we have one switch per GPIO pin, we just get Python to tell us what state it is in when we ask.

So the first thing we will do is import our usual libraries and set the pins to BCM board mode. In GPIO.setup we are going to tell Python to set pins 15 and 18 as inputs.

Creating a while True: loop will create an infinite loop as the condition is always true. While in the loop, we shall store the current state of the input into a variable, and then use an if statement to check if it is a 1 for pressed or a 0 for not pressed. All we are going to do is display on the screen which switch has been pressed; it will also help us work out on which side to place the microswitch.

```
import RPi.GPIO as GPIO
from time import sleep

GPIO.setmode(GPIO.BCM)


GPIO.setup(18, GPIO.IN)
GPIO.setup(15, GPIO.IN)


while True:
  inputleft = GPIO.input(18)
  inputright = GPIO.input(15)
  if inputleft:
    print "Left pressed"
  if inputright:
    print "Right pressed"
  sleep(0.1)
```

Completing the ‘bumping’ robot

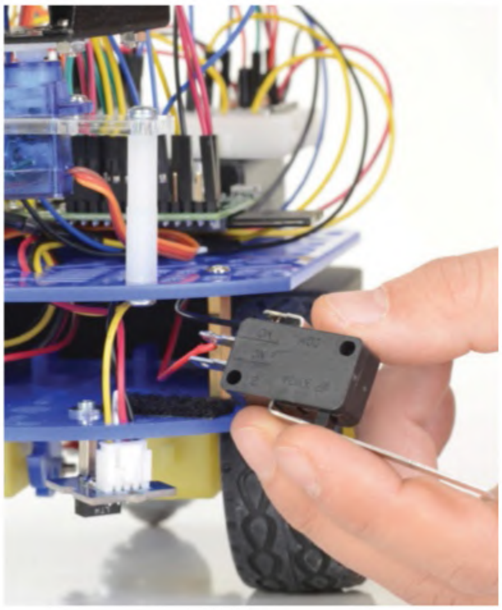
It’s time to add the switches to the robot and find some walls to test it with

We’ll mount the switches to the front of the robot, fixing it down with double-sided tape or Blu-tack so the levers can stick out enough to be pressed when it touches an object. Reusing the motor function code we created before, we can easily add the microswitch support. So this time if an object presses the left microswitch, we tell the motors to switch into reverse for a second and then stop. Hopefully this is long enough to move the robot away from the object so we can now turn just the left-hand motor on for 2 seconds before continuing on its new path. This is a big step - we’re implementing AI and making the robot smart.

Variations can be made to refine our robot, such as creating a reverse for the right-hand motor and having it spin on the spot to create a new path to continue on.

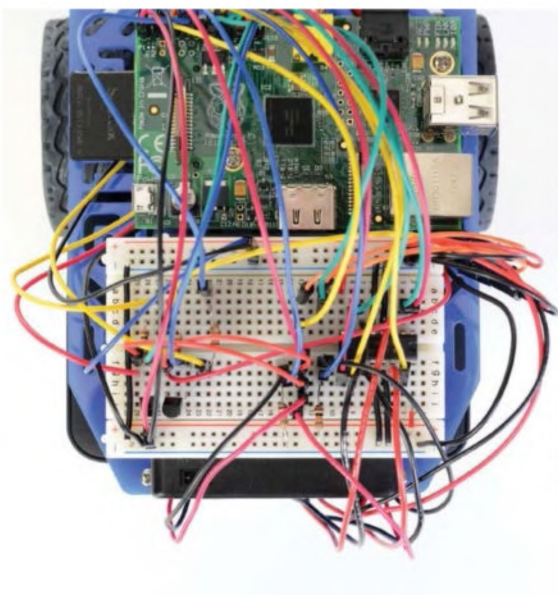
01 Mount the switch

Try to place the microswitches as close to the front of the robot as possible, spaced far enough apart so we can work out what direction the robot is facing when it hits something.



02 Wire it up with the motor circuit

Finding a couple of spare tracks (vertical columns) on the breadboard, add the GPIO jumper cable to the pull-down resistor and connect the switch as shown in the diagram.

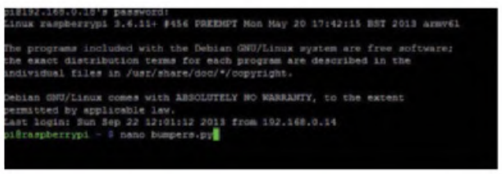


03 Log in with SSH

As our robot will be starting to run around freely, it is a good idea to provide the Raspberry Pi with its own battery. Using Wi-Fi, we can remotely connect using SSH to emulate the Pi’s terminal.

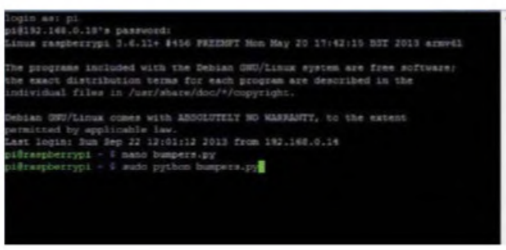
04 Create and save your work

As before with the motors, we shall create our script using nano. Let’s do this by typing `nano bumpers.py`. Saving different scripts allows testing of individual parts. We can also use them as a reference for creating bigger scripts.



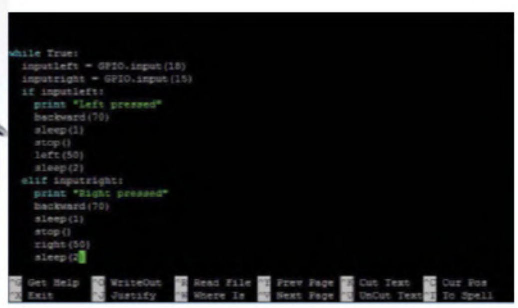
05 Test it in situ

Copying the example script into **bumpers.py**, followed by **Ctrl+X** with a **Y** to save, we can test it out and make any hardware modifications. With the script running, press a microswitch and see what happens!



06 Modify and improve your code

When you first start the script, the motors will start turning forward. Pressing a switch should reverse the motors and spin one motor before going forward again. Play with the variables and tweak its response to what you prefer for it to do.



Bumping robot full code listing

```
import RPi.GPIO as GPIO
from time import sleep

GPIO.setmode(GPIO.BCM)


GPIO.setup(18, GPIO.IN)
GPIO.setup(15, GPIO.IN)

GPIO.setup(24,GPIO.OUT)
GPIO.setup(23,GPIO.OUT)
GPIO.setup(25,GPIO.OUT)
GPIO.setup(9,GPIO.OUT)
GPIO.setup(10,GPIO.OUT)
GPIO.setup(11,GPIO.OUT)

Motor1 = GPIO.PWM(25, 50)
Motor1.start(0)
Motor2 = GPIO.PWM(11, 50)
Motor2.start(0)

def forward(speed):
  GPIO.output(24,GPIO.HIGH)
  GPIO.output(23,GPIO.LOW)
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor1.ChangeDutyCycle(speed)
  Motor2.ChangeDutyCycle(speed)

def backward(speed):
  GPIO.output(24,GPIO.LOW)
  GPIO.output(23,GPIO.HIGH)
  GPIO.output(9,GPIO.LOW)
  GPIO.output(10,GPIO.HIGH)
  Motor1.ChangeDutyCycle(speed)
  Motor2.ChangeDutyCycle(speed)

def left(speed):
  GPIO.output(24,GPIO.HIGH)
  GPIO.output(23,GPIO.LOW)
  Motor1.ChangeDutyCycle(speed)

def right(speed):
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor2.ChangeDutyCycle(speed)

def stop():
  Motor1.ChangeDutyCycle(0)
  Motor2.ChangeDutyCycle(0)


while True:
  inputleft = GPIO.input(18)
  inputright = GPIO.input(15)
  if inputleft:
    print “Left pressed”
    backward(100)
    sleep(1)
    stop()
    left(75)
    sleep(2)
  elif inputright:
    print “Right pressed”
    backward(100)
    sleep(1)
    stop()
    right(75)
    sleep(2)
  else:
    forward(75)
  sleep(0.1)
```

DON’T FRY THE PI!

It is important to check the specifications of any sensor to make sure it is compatible with 3.3V power supply.

DIGITAL SWITCHES

A switch is a perfect digital signal, as it can only be one of two states: on or off.

Line-following sensors

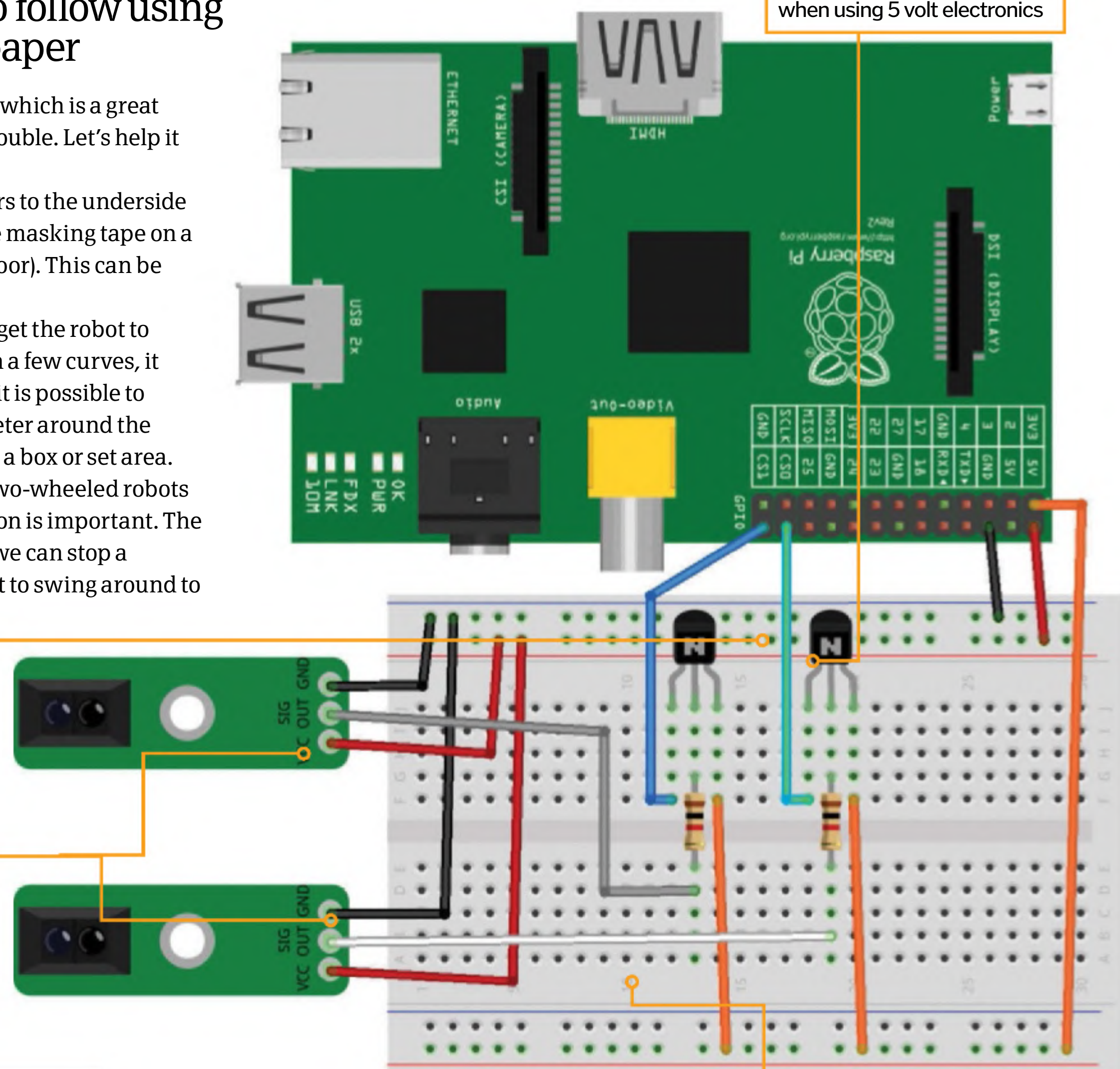
Give your robot a track to follow using masking tape or inked paper

So far the robot can decide its own path, which is a great thing for it to do, but it could end up in trouble. Let's help it follow a set path.

One solution is to add some line sensors to the underside so we are able to control it by using some masking tape on a dark floor (or some dark tape on a light floor). This can be used in a number of different ways.

By marking a line on the floor, we can get the robot to follow it obediently; even by throwing in a few curves, it should be able to navigate a set path. Or it is possible to tackle it another way by adding a perimeter around the robot, allowing us to restrict the robot to a box or set area.

Line following is best achieved with two-wheeled robots as their ability to quickly change direction is important. The principal is that as a sensor is triggered we can stop a corresponding motor, allowing the robot to swing around to stay on the line.



SAFETY FIRST
Thanks to the transistor, we have a much safer voltage going back into the GPIO pins when using 5 volt electronics

LOWER THE CURRENT
The transistors only need a small amount of current to actually work; a resistor helps to smooth out the sensors' output

LINE SENSORS
Sensors come in a variety of shapes and sizes, but most have a common set of pins; the important one is the OUT pin

MAKING VOLTAGE SAFER
Transistors work just like a switch, being able to turn power on and off. Using it to switch the 3.3V power to the GPIO is a much safer method

POWER
Most sensors are only available in 5 volt form; we need a transistor to switch the voltage to a Raspberry Pi-safe level

Parts list

- Breadboard
- Jumper cables
- 2x 2N3904 transistors
- 2x 1K resistors
- 2x Line detector sensors

Testing the line sensors

With the line sensors wired up and the Raspberry Pi switched on, we can now test them. This Python script is very similar to the microswitch test code as we are just reading the GPIO pin's status, checking if it is high (a 1 or on) or if it is low (0 or off).

As some sensors work differently to others, we need help to understand the output. Displaying the current sensor data on the screen allows us to work out how the sensor responds on black and white surfaces and plan the code accordingly.

01 Start your project

Start a terminal on your Raspberry Pi and create the **linefollow.py**script: `nano linefollow.py`. This will be our test script for the finished line-following robot.

02 Read the sensors

Copy the test script into the file. As each sensor is slightly different, we may need to tweak the code slightly to suit, so test what you have and interpret the output.

03 Print to screen

Save the file as before. You'll notice the code we've supplied has **print** statements to show if the sensor is picking up any difference between light and dark surfaces.

04 We have data

If everything is wired up correctly, the screen will start filling up with sensor data, letting us know if it can see black or white. Put some paper in front of the sensor to try it out.

```
import RPi.GPIO as GPIO
from time import sleep

GPIO.setmode(GPIO.BCM)

Input1 = 7
Input2 = 8

GPIO.setup(Input1,GPIO.IN)
GPIO.setup(Input2,GPIO.IN)

while True:
  Sensor1 = GPIO.input(Input1)
  Sensor2 = GPIO.input(Input2)

  if Sensor1 == GPIO.HIGH:
    print "Sensor 1 is on White"
  else:
    print "Sensor 1 is on Black"

  if Sensor2 == GPIO.HIGH:
    print "Sensor 2 is on White"
  else:
    print "Sensor 2 is on Black"

  print "------"
  sleep(1)

GPIO.cleanup()
```

Finalise your line-following bot

It can see! Now put its new eyes to good use…

By now we should be used to controlling the motors, so building on that knowledge we can start to concentrate on the sensors. Most line followers use the same convention as microswitches, giving a high output to signal the sensor is over a black surface and a low output (or off) to signal it's over a white surface.

When using a white masking tape line, we want the motor to stop when the sensor is touching the line, giving the other side a chance to turn the robot to correct its position.

The code is nice and simple, so it can be easily modified to suit your own situation.

01 Mount the sensor

Using the hexagonal mounting rods, mount the sensors at about 10mm to cope with uneven floors. Most sensors will be sensitive enough at that distance; if not, there will be a potentiometer to adjust the sensitivity.

BIG BUSINESS

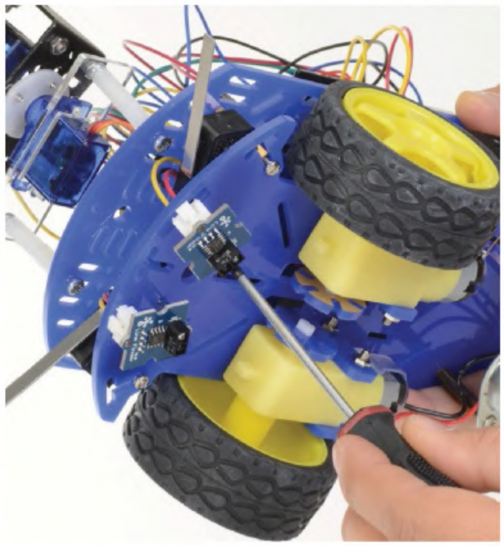
Some manufacturing plants use lines to guide robots around warehouses in an identical way to our robot, but on a much larger scale.

02 Adding to your breadboard

There should be plenty of room on your robot's breadboard, but make sure you use all the available 'tracks'. Keep your different types of sensors in their own little areas – get to know them so you can debug the hardware easily.

03 Add the sensor circuit

Place the two transistors and resistors on the breadboard, checking each pin is in its own column. Add the jumper cables from the sensors and power lines, and then to the GPIO pins.



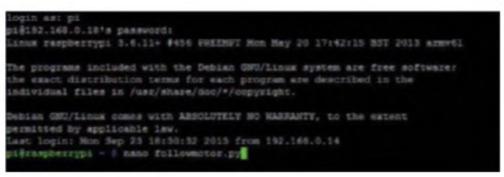
04 Power up and log on

Connect the batteries for the motors and add power to the Raspberry Pi. Now log in using SSH on your computer so we are able to create our motor-controlled line sensor code.

```
login as: pi
pi@192.168.0.18's password:
Linux raspberrypi 3.6.11+ #456 PREEMPT Mon May 20 17:42:15 BST 2013 armv6l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Sun Sep 22 12:01:12 2013 from 192.168.0.14
pi@raspberrypi ~ $
```

05 Creating the script

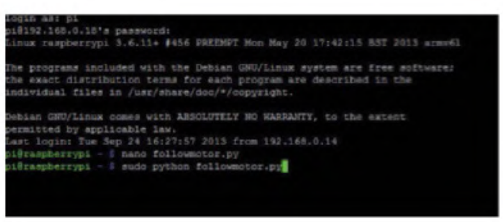
As you can see, the code for the line-following robot is quite similar to our previous code. **While True:** ensures the code loops until we stop it, and we've kept some **print** statements in for debugging purposes.



```
login as: pi
pi@192.168.0.18's password:
Linux raspberrypi 3.6.11+ #456 PREEMPT Mon May 20 17:42:15 BST 2013 armv6l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Mon Sep 23 18:50:32 2013 from 192.168.0.14
pi@raspberrypi ~ $ nano followmotor.py
```

06 Testing your new script

All being well, your robot will now scoot off and find a line to follow. There are plenty of ways to improve and add to this code to make the bot's movements along the line smoother. It's also quite trivial to build this into your existing code.



```
login as: pi
pi@192.168.0.18's password:
Linux raspberrypi 3.6.11+ #456 PREEMPT Mon May 20 17:42:15 BST 2013 armv6l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Tue Sep 24 16:27:57 2013 from 192.168.0.14
pi@raspberrypi ~ $ nano followmotor.py
pi@raspberrypi ~ $ sudo python followmotor.py
```

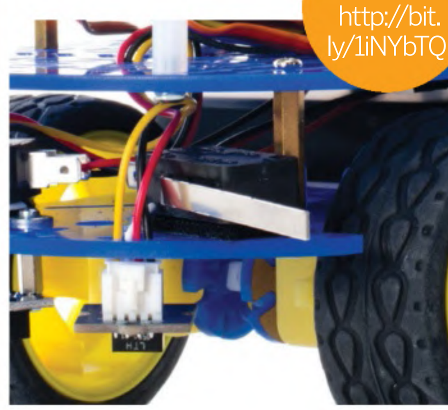
Bumping robot full code listing

```
import RPi.GPIO as GPIO
from time import sleep

GPIO.setmode(GPIO.BCM)


GPIO.setup(7, GPIO.IN)
GPIO.setup(8, GPIO.IN)

GPIO.setup(24,GPIO.OUT)
GPIO.setup(23,GPIO.OUT)
GPIO.setup(25,GPIO.OUT)
GPIO.setup(9,GPIO.OUT)
GPIO.setup(10,GPIO.OUT)
GPIO.setup(11,GPIO.OUT)

Motor1 = GPIO.PWM(25, 50)
Motor1.start(0)
Motor2 = GPIO.PWM(11, 50)
Motor2.start(0)

def forward(speed):
  GPIO.output(24,GPIO.HIGH)
  GPIO.output(23,GPIO.LOW)
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor1.ChangeDutyCycle(speed)
  Motor2.ChangeDutyCycle(speed)

def backward(speed):
  GPIO.output(24,GPIO.LOW)
  GPIO.output(23,GPIO.HIGH)
  GPIO.output(9,GPIO.LOW)
  GPIO.output(10,GPIO.HIGH)
  Motor1.ChangeDutyCycle(speed)
  Motor2.ChangeDutyCycle(speed)

def left(speed):
  GPIO.output(24,GPIO.HIGH)
  GPIO.output(23,GPIO.LOW)
  Motor1.ChangeDutyCycle(speed)

def right(speed):
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor2.ChangeDutyCycle(speed)

def stop():
  Motor1.ChangeDutyCycle(0)
  Motor2.ChangeDutyCycle(0)


while True:
  sensor1 = GPIO.input(7)
  sensor2 = GPIO.input(8)
  if sensor1 == GPIO.LOW:
    print "Sensor 1 is on white"
    stop()
  else:
    left(60)
  if sensor2 == GPIO.LOW:
    print "Sensor 2 is on white"
    stop()
  else:
    right(60)
  sleep(0.05)
```

SUDO PYTHON?

Prefix with sudo to elevate a program's permission level to a superuser. It's required to control the GPIO pins from Python, so don't forget it!

Get the code: http://bit.ly/1iNYbTQ



Ultrasonic sensing

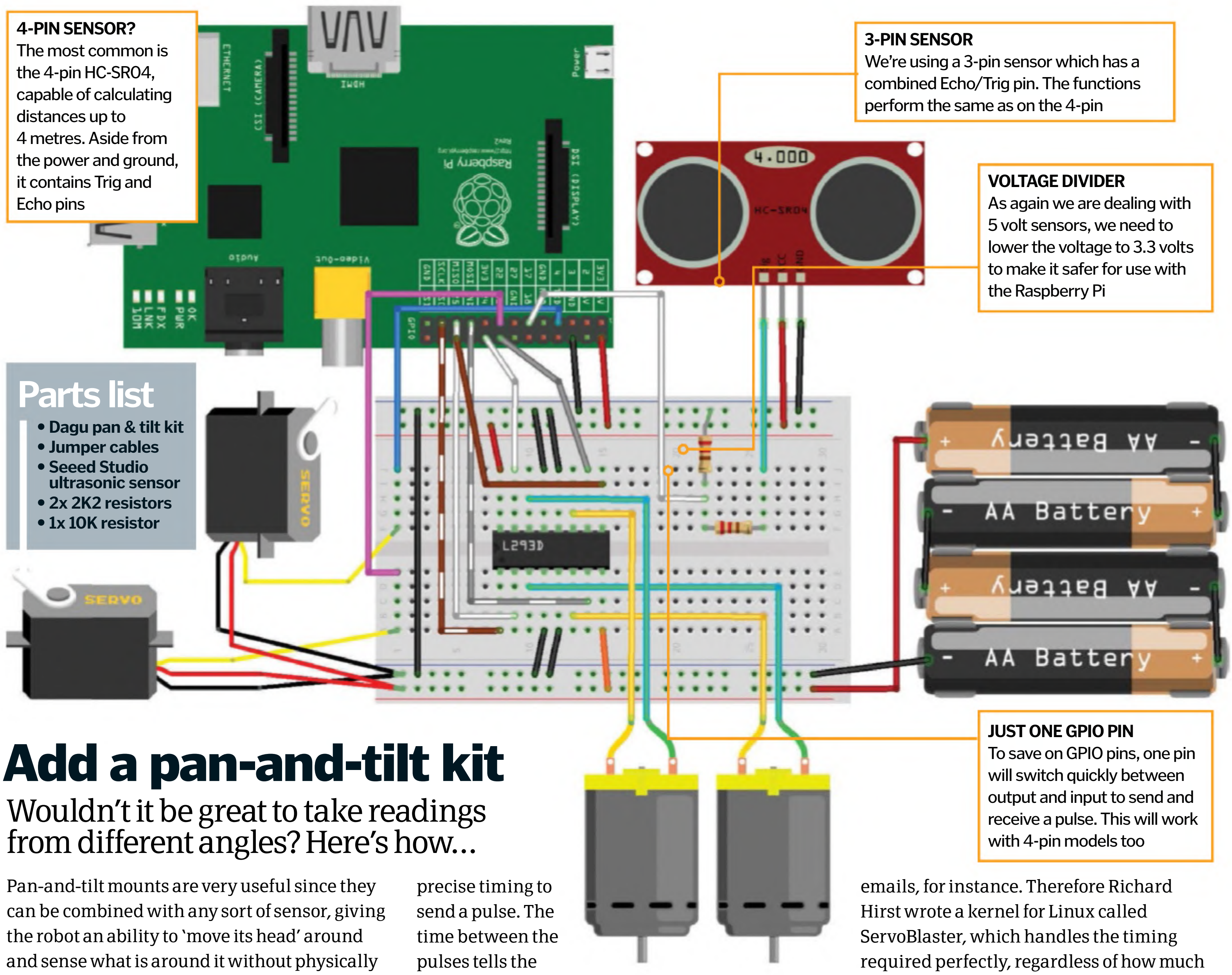
Give your robot a track to follow using masking tape or inked paper

Let's start making things a little more complicated by adding an ultrasonic sensor and placing it onto a pan-and-tilt mounting. Ultrasonic sensors are used in different ways to judge distance by emitting an ultrasonic pulse and counting how long it takes to bounce off an object then back to the receiver. Cars that come with reverse parking sensors work in the same way to give an audible tone depending on how far away an object is.

Using an ultrasonic sensor on your robot will give it a chance to take action as it approaches an object such as a wall, with enough time to evaluate and choose a new path.

Ultrasonic sensors come in two varieties, based on the number of pins. Both types work in a very similar way. Since we would like to use the same Python code for both, we would wire the 4-pin sensor to act like a 3-pin ultrasonic sensor. However, we will focus on the affordable 3-pin model from Dawn Robotics. As we only require one GPIO pin, we will first need to set it as an output and send a 10ms pulse to trigger the sensor to start and begin counting.

Next we switch to an input to wait for the pin to go high, at which point we stop timing and calculate how long that took. The last thing needed is to convert the time in sound into a measurement we can read, which in this case is the number of centimetres.



4-PIN SENSOR?
The most common is the 4-pin HC-SR04, capable of calculating distances up to 4 metres. Aside from the power and ground, it contains Trig and Echo pins

3-PIN SENSOR
We're using a 3-pin sensor which has a combined Echo/Trig pin. The functions perform the same as on the 4-pin

VOLTAGE DIVIDER
As again we are dealing with 5 volt sensors, we need to lower the voltage to 3.3 volts to make it safer for use with the Raspberry Pi

Parts list
- Dagu pan & tilt kit
- Jumper cables
- Seeed Studio ultrasonic sensor
- 2x 2K2 resistors
- 1x 10K resistor

JUST ONE GPIO PIN
To save on GPIO pins, one pin will switch quickly between output and input to send and receive a pulse. This will work with 4-pin models too

Add a pan-and-tilt kit

Wouldn't it be great to take readings from different angles? Here's how…

Pan-and-tilt mounts are very useful since they can be combined with any sort of sensor, giving the robot an ability to 'move its head' around and sense what is around it without physically moving its body. The pan-and-tilt is controlled by two special motors called servos.

Servos allow very precise movement within their range, typically between 0 and 180 degrees. They do this by using some very precise timing to send a pulse. The time between the pulses tells the servo its angle.

Typically the Raspberry Pi, being a not-so-great real-time device, would sometimes struggle maintaining a steady pulse, as it could forget what it was doing and go off to check some emails, for instance. Therefore Richard Hirst wrote a kernel for Linux called ServoBlaster, which handles the timing required perfectly, regardless of how much is happening. The kernel takes control of some of the timing registers to provide an accurate clock. All that is required is to send the angle you need to /dev/servoblaster and the servo will spring to life!

The complete ultrasonic code listing

```
import RPi.GPIO as GPIO
from time import sleep
from time import time
import os

GPIO.setmode(GPIO.BCM)

GPIO.setup(24,GPIO.OUT)
GPIO.setup(23,GPIO.OUT)
GPIO.setup(25,GPIO.OUT)
GPIO.setup(9,GPIO.OUT)
GPIO.setup(10,GPIO.OUT)
GPIO.setup(11,GPIO.OUT)

Motor1 = GPIO.PWM(25, 50)
Motor1.start(0)
Motor2 = GPIO.PWM(11, 50)
Motor2.start(0)

Echo = 17
Pan = 22
Tilt = 4

def forward(speed):
  GPIO.output(24,GPIO.HIGH)
  GPIO.output(23,GPIO.LOW)
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor1.ChangeDutyCycle(speed)
  Motor2.ChangeDutyCycle(speed)

def backward(speed):
  GPIO.output(24,GPIO.LOW)
  GPIO.output(23,GPIO.HIGH)
  GPIO.output(9,GPIO.LOW)
  GPIO.output(10,GPIO.HIGH)
  Motor1.ChangeDutyCycle(speed)
  Motor2.ChangeDutyCycle(speed)

def left(speed):
  GPIO.output(24,GPIO.HIGH)
  GPIO.output(23,GPIO.LOW)
  Motor1.ChangeDutyCycle(speed)

def right(speed):
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor2.ChangeDutyCycle(speed)

def stop():
  Motor1.ChangeDutyCycle(0)
  Motor2.ChangeDutyCycle(0)


def get_range():
  GPIO.setup(Echo,GPIO.OUT)
  GPIO.output(Echo, 0)
  sleep(0.1)
  GPIO.output(Echo,1)
  sleep(0.00001)
  GPIO.output(Echo,0)

  GPIO.setup(Echo,GPIO.IN)
  while GPIO.input(Echo) == 0:
    pass
  start = time()
  while GPIO.input(Echo) == 1:
    pass
  stop = time()
  elapsed = stop - start
  distance = elapsed * 17000
  return distance


while True:
  distance = get_range()
  if distance < 30:
    print "Distance %.1f " % distance
    stop()
    string = "echo 0=10 > /dev/
servoblaster"
    os.system(string)
    sleep(1)
    disleft = get_range()
    print "Left %.1f " % disleft

    string = "echo 0=360 > /dev/
servoblaster"
    os.system(string)
    sleep(1)
    disright = get_range()
    print "Right %.1f " % disright

    if disleft < disright:
      print "Turn right"
      left(100)
      sleep(2)
    else:
      print "Turn left"
      right(100)
      sleep(2)

    os.system("echo 0=160 > /dev/
servoblaster")

  else:
    forward(80)
    print "Distance %.1f " % distance

  sleep(0.5)
GPIO.cleanup()
```

Get the code: http://bit.ly/1iNYbTQ

Installing your pan & tilt

It's a fiddly job, but well worth the trouble

Now we've taken care of the circuit, let's set them up; first we need to get the kernel so let's download that now, so type the following into your RasPi terminal: `wget https://github.com/Boeeerb/LinuxUser/raw/master/servod`

And make it executable:

`chmod +x servod`

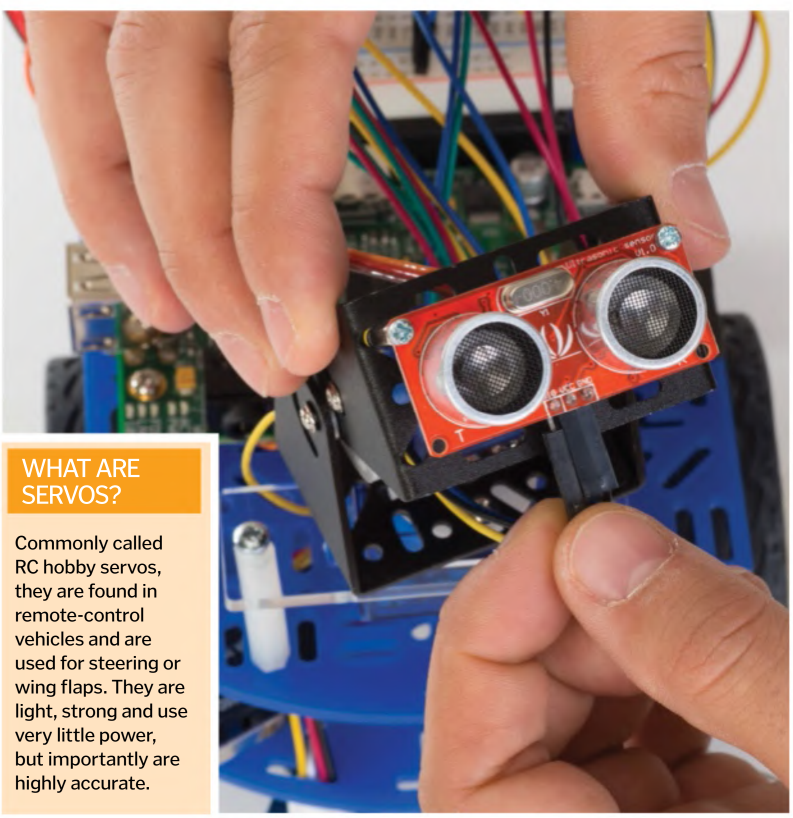
Lastly, run it – remember, every time you reboot or switch on your Pi, you will just need to type this line:

`sudo ./servod`

The pre-compiled kernel is already configured to use pins 4 and 22 as servos, so let's hook everything up.

The servos will need to be powered separately as they are at heart just motors with a little bit of circuitry.

The code we have will combine the wheel motors, servos and ultrasonic. The end result will involve the robot moving forward until it senses an object less than 30cm away, stop, then turn the pan-and-tilt left, check the distance, then turn the ultrasonic on the pan-and-tilt right and pick whichever direction has a further distance until the next object.



WHAT ARE SERVOS?

Commonly called RC hobby servos, they are found in remote-control vehicles and are used for steering or wing flaps. They are light, strong and use very little power, but importantly are highly accurate.

01 Assemble the kit

The pan-and-tilt mount allows a full view of 180 degrees from left to right, up and down – great for adding ultrasonics or even a camera. The servos give the perfect control for this.

02 Connect the servos

The servos are still a motor, so it is advisable to give them their own power separate from the Raspberry Pi. Take note of the voltage required; most allow up to 6 volts, some less. It can share the same batteries as the motors.

03 Don't forget the kernel

To get full control over the servos, we need **servod** (ServoBlaster) running. So download this and make it executable with `chmod +x servod` and run it with `sudo ./servod`.

04 Create your script

Now we can create the test script. You can copy and paste our creation from the disc, or better yet write it out as above and get your code-writing muscle memory working!

05 And she's off...

When you set off the script, the screen should fill with distance data so we can see what is happening and check on the direction it decides to take. It may pose a challenge if it gets stuck in a corner - see if you can debug it.

06 Debugging problems

If the robot doesn't act like it should, or the servo goes the wrong way, just swap the servo data pins around. Double-check your code and give it another try.

"The end result is the robot moving forward until it senses an object less than 30cm away"

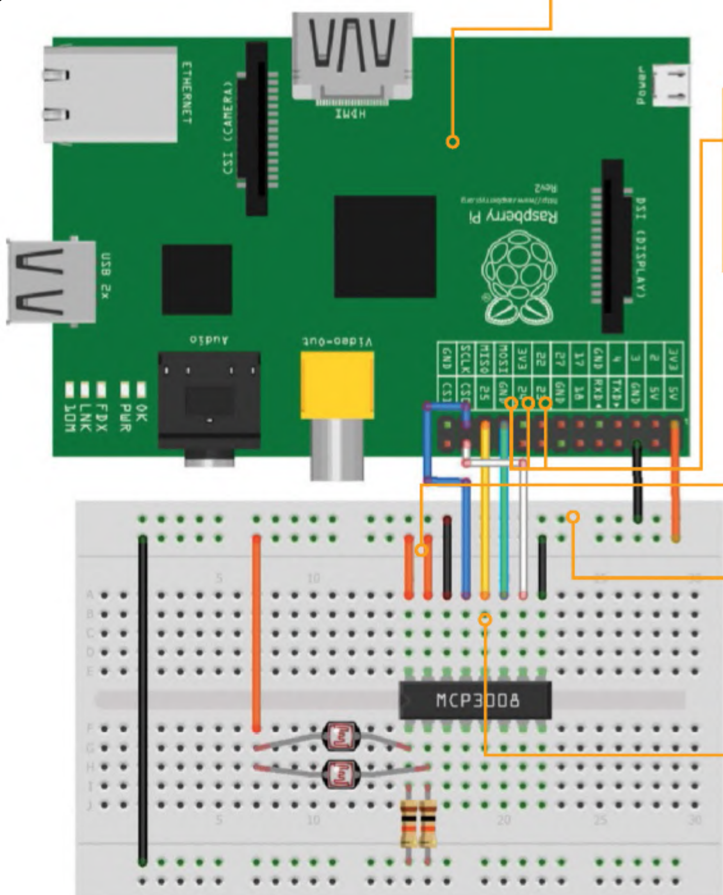
Use analogue sensors

Open your robot up to a new world of input

As we've already shown using microswitches and ultrasonic sensors, the Raspberry Pi is very capable of taking inputs and performing actions based on the outside world. Inputs also come in a variety of different types. Most common are digital sensors such as buttons and switches, but there are also analogue sensors which can be used to read temperatures or brightness. These sensors give their data in the form of a voltage value.

The Raspberry Pi is unable to read an analogue signal natively, so a little help is required and this comes in the form of a microchip called an MCP3008. This chip is commonly referred to as an ADC (analogue-to-digital converter). It can communicate with the Raspberry Pi via serial and is capable of reading eight analogue inputs at once and giving their voltage in the form of a number: 0 will correspond to the lowest, while 1023 is the maximum voltage.

Using analogue, we can build a robot that is capable of following (or avoiding) bright light – perfect if you wish to have a plant pot follow the sun during the day.



Parts list

- 1x MCP3008
- 2x Light-dependent resistors (LDRs)
- 2x 10K resistors
- Jumper wires

Test, test and test again

Like good computer scientists we'll check it works first

Now we have wired the ADC, we need to make sure it works. So before we add it into our robot we shall use Python to read the values and display them on the screen.

Doing this will help get an overall idea of what to expect when the sensor is in bright light, and how different the numbers will be when they are in the dark.

Before we can interface with the MCP3008, we need enable the serial drivers and install a Python library called spidev, so let's do this before anything else.

Open up a terminal, or connect to your Raspberry Pi, and then type in the following commands:

```
sudo nano /etc/modprobe.d/raspi-blacklist.conf
```

And add a # to the start of each line in the file, then...

```
sudo apt-get install python-pip python-dev
sudo pip install spidev
sudo reboot
```

Once this is done, we are now free to start reading some analogue sensors!

The first two lines in our test code are there to tell Python what libraries we need. Now we need to tell Python to create a new instance and tell it what channel our MCP3008 chip is on, this is handled by the next two lines.

We are nearly ready, so we'll define a function which will handle communication and returning it to our script so that we can act upon its value called 'get_value'.

From left to right on the chip the channels start at zero and go all the way to seven, so using this we combine with the get_value function to retrieve our value.

```
import spidev
import time

spi = spidev.SpiDev()
spi.open(0,0)


def get_value(channel):
  if ((channel > 7) or (channel < 0)):
    return -1

  r = spi.xfer2([1,(8+channel)<<4,0])

  ret = ((r[1]&3) << 8) + (r[2] >> 2)
  return ret


while True:
  print "Chan 0: " + str(get_value(0))
  print "Chan 1: " + str(get_value(1))
  time.sleep(0.3)
```

> "The Raspberry Pi is very capable of taking inputs and performing actions based on the outside world"

Sensing light with the Raspberry Pi

With everything connected up, let's go chase some light

Hopefully we now have a set of numbers scrolling down the screen, and have tested it by covering a sensor or shining a torch to see how it affects the readings.

Now we can mount the LDRs to the front of the robot to allow it to sense the level of light. The aim now is to tell the robot to move forward at a slower pace, using a speed of 75. As the LDRs are constantly checking the light levels, if one should rise above 600 (as a result of a torch shining at it, for instance) it will prompt the opposite wheel to speed up to turn towards the light.

As each lighting situation will be slightly different, perform the test script to get an idea of the values that will be expected from the LDRs. These will fluctuate depending on the ambient light levels.

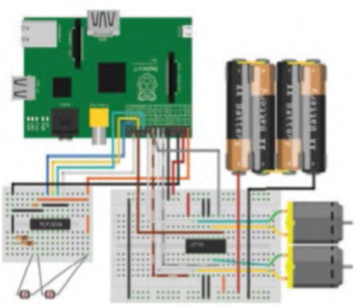
> "Perform the test script to get a better idea of the values that will be expected from the LDRs"

EXPERIMENT

Try stopping the bot when the light goes below a value; or if a torch shines on an LDR sensor, spin around for 5 seconds.

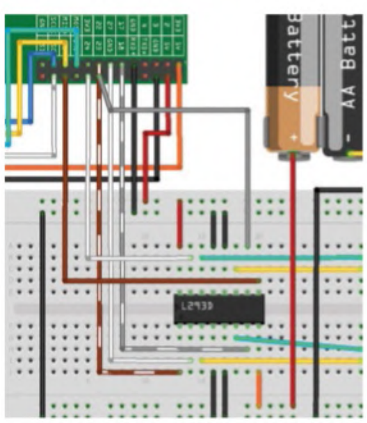
01 Mount the LDRs

It is best to place them apart, pointing outwards,to get a good idea of the different lighting available. If the wiring on the breadboard starts getting difficult, add another breadboard to separate the two ICs.



02 Change the motors

As we are using the SPI serial bus for the MCP3008 communication, we will need to move the motor driver pins to a different set of GPIO pins, so we shall switch pins 8, 9 and 10 to 22, 27/21 and 17.

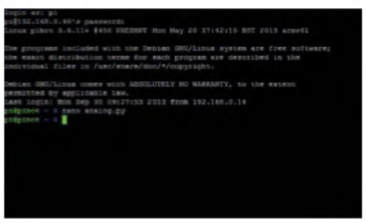


03 Double-check everything

As we have a lot of power types – we are using 3V3 for the MCP3008, 5V to the L293D and also the batteries – it is best to check they are all correctly wired up. Once it looks good, add some power and log into the Pi.

04 Create the script

Once everything is connected, we shall use nano to write our Python script: type `nano analog.py` to create the file. Copy the code. Exit nano with **Ctrl+X** and then **Y** and **Enter** to save the file. It should be second nature by now!

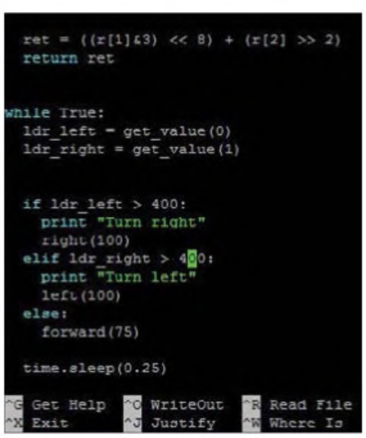


05 Run the script

All that is required is to type `sudo python analog.py` to run the program. The robot should start to follow the brightest light source. If not, check your code and connections or go back to the testing code to debug.

06 Something is wrong

If you're sure it's working properly, it could be that a tweak to the value may be needed. Run the test script again to get a suitable number to replace the 600 that is currently used. Remember – testing at different times of day may require you to change some of your variables as light levels change.



Get the code: http://bit.ly/1iNYbTQ

The complete analog code listing

```
import spidev
import time

spi = spidev.SpiDev()
spi.open(0,0)

GPIO.setmode(GPIO.BCM)

GPIO.setup(27,GPIO.OUT)
GPIO.setup(17,GPIO.OUT)
GPIO.setup(22,GPIO.OUT)
GPIO.setup(9,GPIO.OUT)
GPIO.setup(10,GPIO.OUT)
GPIO.setup(11,GPIO.OUT)

Motor1 = GPIO.PWM(22, 50)
Motor1.start(0)
Motor2 = GPIO.PWM(11, 50)
Motor2.start(0)


def forward(speed):
  GPIO.output(27,GPIO.HIGH)
  GPIO.output(17,GPIO.LOW)
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor1.
ChangeDutyCycle(speed)
  Motor2.
ChangeDutyCycle(speed)

def backward(speed):
  GPIO.output(27,GPIO.LOW)
  GPIO.output(17,GPIO.HIGH)
  GPIO.output(9,GPIO.LOW)
  GPIO.output(10,GPIO.HIGH)
  Motor1.
ChangeDutyCycle(speed)
  Motor2.
ChangeDutyCycle(speed)

def left(speed):
  GPIO.output(27,GPIO.HIGH)
  GPIO.output(17,GPIO.LOW)
  Motor1.
ChangeDutyCycle(speed)

def right(speed):
  GPIO.output(9,GPIO.HIGH)
  GPIO.output(10,GPIO.LOW)
  Motor2.
ChangeDutyCycle(speed)

def stop():
  Motor1.ChangeDutyCycle(0)
  Motor2.ChangeDutyCycle(0)

def get_value(channel):
  if ((channel > 7) or
(channel < 0)):
    return -1

  r = spi.
xfer2([1,(8+channel)<<4,0])

  ret = ((r[1]&3) << 8) +
(r[2] >> 2)
  return ret

while True:
  ldr_left = get_value(0)
  ldr_right = get_value(1)

  if ldr_left > 600:
    print "Turn right"
    right(100)
  elif ldr_right > 600:
    print "Turn left"
    left(100)
  else:
    forward(75)

  time.sleep(0.25)
```

MCP3008/ MCP3004

A smaller ADC chip called the MCP3004 is also available, it only has 4 analogue channels as opposed to 8 with the MCP3008.

> "Testing at different times of day may require you to change some variables"

What next?

So you've finished building our project robot and you're wondering what's next...

There are loads of choices, which is one of the attractive things about robotics, and really you're only limited by your time and imagination.

You could choose to expand your robot's hardware, adding more sensors as your knowledge and confidence improves, so that your robot can learn more about the world. Gas, light and sound... for practically any stimulus you can imagine, there's the corresponding sensor that you can add to your robot. With a bigger platform, you could also add an arm to your robot so it doesn't just sense the world – it can also pick up bits of the world and move them around.

You could expand your robot by giving it the means to communicate with people it meets in its environment. Speakers are one way of doing this, but flashing LEDs or lines of electroluminescent (EL) wire are other ways in which a robot can indicate its internal state. The more creative the better here: robotics can be as much of an artistic pursuit as a technical one.

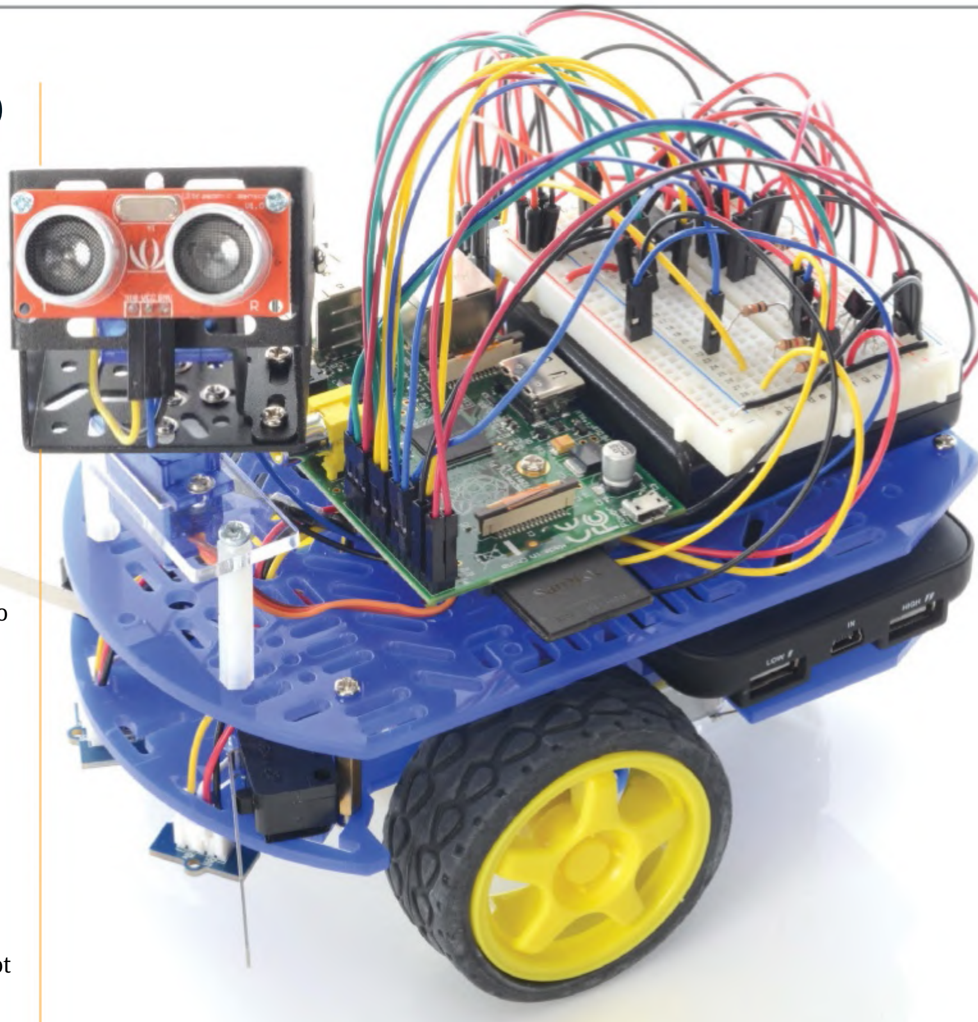
With the computing power of the Raspberry Pi on board, you also have the space to expand the software of your robot and boost its intelligence. Using a webcam or the Pi camera board for computer vision is probably one of the most popular options – and luckily, OpenCV, a very comprehensive open source computer vision library, is available to get you started quickly. You could use it to allow your robot to recognise faces, to search for interesting objects in its environment, or to quickly recognise places it's been before.

Don't think that you have to limit yourself to just one robot, however. Swarm robotics is a very interesting branch of robotics that seeks to draw inspiration from the intelligence exhibited by swarms of insects in the natural world. It's fascinating to consider how complex behaviours can be built up from the interactions of a number of simple robots. Your robots can communicate over Wi-Fi, or via a central computer. Alternatively, you can give the robots more 'local' communication using IR LEDs and receivers to communicate with their neighbours.

Whatever you decide to do with your Raspberry Pi robot, and whichever direction you end up taking it in, remember to show and tell the rest of the Raspberry Pi community what you've done! There are lots of friendly, and knowledgeable, people in the open source communities surrounding the Raspberry Pi, lots of whom are also making robots. Places like the Raspberry Pi forum can be a great source of advice and support as you attempt to build your dream robot.

Alan Broun, MD of DawnRobotics.co.uk

"Robotics can be an artistic pursuit and a technical one"



Facial recognition

Let the robot know who's boss

With the simple addition of the Raspberry Pi's camera module and OpenCV software, face detection and recognition is possible. You could do this by replacing the ultrasonic from the pan-and-tilt mount with the camera; this will allow the camera to move and follow your movements.

Learning to talk

Get a new insight into your robot's state

The Raspberry Pi comes with an audio output. So combining this with a travel speaker will unlock a new world of communication for your robot.

Using a Python-friendly speech module like eSpeak, you can teach your robot to talk, sing or simply report readings for debugging purposes. This can add another human element to your creation, but adding speech recognition with a USB microphone, or similar, can take it to a whole new level.

Spatial analysis

Make accurate maps of your surroundings

Using the ultrasonic sensor with the pan-and-tilt kit on your robot, you can effectively measure every wall and every object in a room – a popular specialism in computer science.

So by taking a series of measurements in different directions, controlled by the servos in the pan-and-tilt mount, it is possible to make a map. With another sprinkling of code and gadgetry, you could teach your bot to navigate your house. PID is an excellent field that can certainly help with this.

Maze solving

Outperform a lab rat

Path finding and maze solving are other exciting branches of computer science you can attempt with your RasPi robot. Competitions are held around the world to be the fastest to solve a maze, using lines on the floor or ultrasonic sensors. All you need is a mechanism to recall past movements and a scientific approach to the robot's attitude to maze solving.

Swarming

One robot is cool, a bunch is better

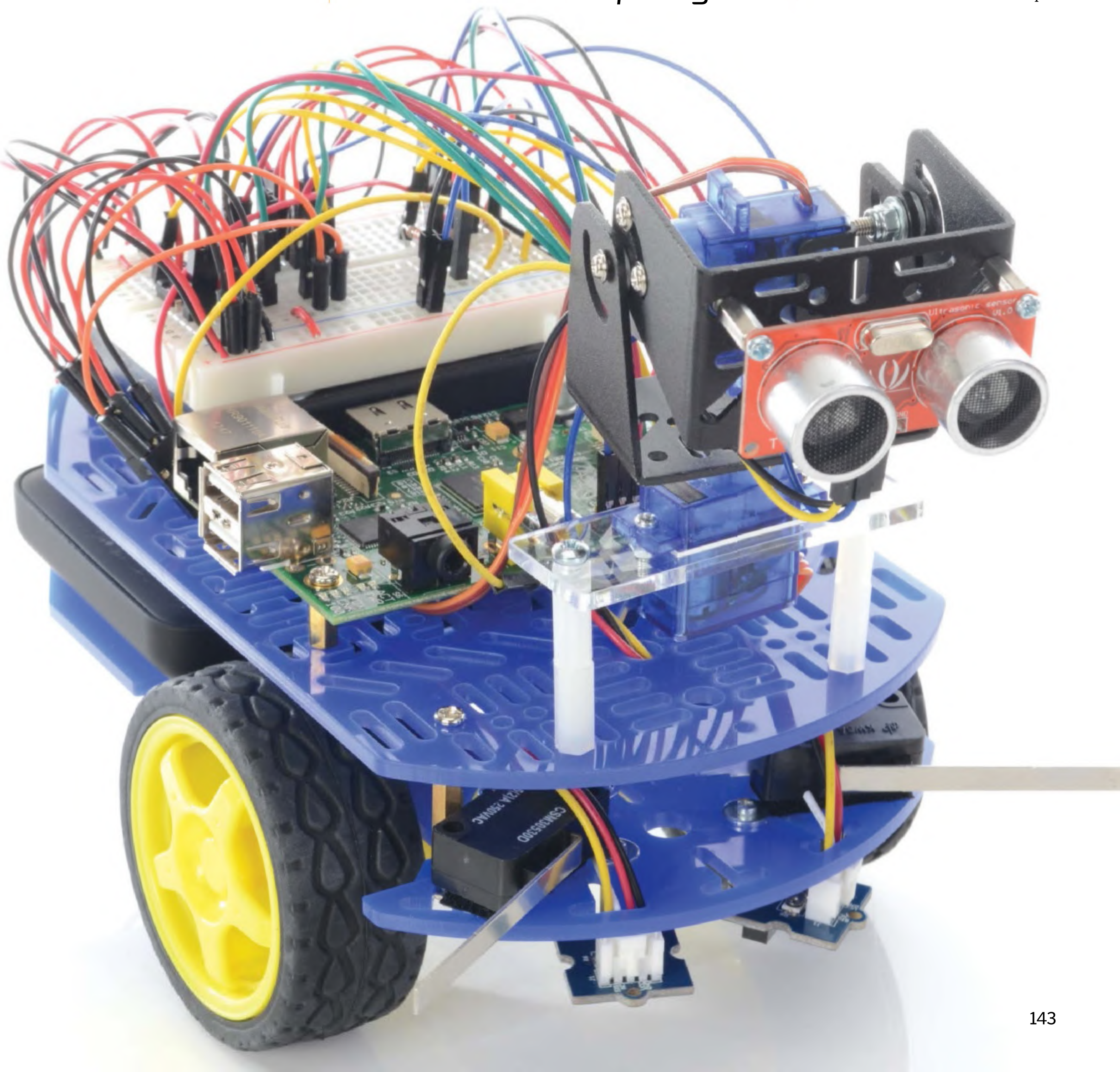
Swarming is an interesting branch of computer science. Using just a little more code than we already have, we can create behaviour similar to that of a swarm of bees, or ants. A swarm of robots could discover an area quickly, or be used to scientifically model traffic-calming measures. You could even create your own synchronised routines, or build a robot football team.

"A swarm of robots could discover an area quickly"

Robot arm

Make the robot get it

Everyone would love a robotic helper, perfect for performing tasks around the house. Unfortunately we aren't there yet, but we can come close. By mounting a small gripper arm to the front of the robot, it can fetch lightweight items. With the help of the Pi camera module, or an RGB colour sensor, you could colour-sort LEGO bricks or entertain a pet.



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HOW IT WORKS

BOOK OF

ROBOTS

OVER 50 ROBOTS INSIDE

DISCOVER THE AMAZING ANDROIDS CHANGING THE WORLD

10 BEST BOTS

DISCOVER THE AMAZING ROBOTS YOU CAN OWN, RIGHT NOW

THE FIRST ROBOTS

MEET THE MACHINES THAT PIONEERED ROBOTICS IN THEIR FIELDS

DRIVERLESS CARS

DO THEY SPELL THE END FOR DRIVERS, AND HOW DO THEY AVOID CRASHING?

ROBOTS IN SPACE

THE PROBES AND BOTS MAKING SPACE DISCOVERIES POSSIBLE

MAKE YOUR OWN ROBOT

USE A RASPBERRY PI TO CREATE AND PROGRAM THE ULTIMATE MINI ROBOT